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INVENTORY ACCURACY IN A DYNAMIC PRODUCTION NETWORK

– Case ABB Drives

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Abstract

With the help of enterprise resource planning systems, stock is monitored and measured every day in most manufacturing and retailing companies. In these organizations, daily operations depend on the accuracy of inventory data. Erroneous inventory records may have significant adverse effects on operational functionality. The main problems appear through ineffective stock order decisions, which may result in late deliveries to customers, future lost sales, idle time for production lines or unnecessary stock that ties financial resources and warehouse space.

Despite the direct effects caused by inaccurate material accounting, its significance is rarely acknowledged in the literature. This study focuses in inventory accuracy problems faced by a large electronics manufacturer and its partner network. All stock is owned by the case company, whose responsibility is to keep track of millions of individual components and finished products spread over multiple facilities, in a constantly changing situation that is managed under one single IT-system. This type of environment has become increasingly popular throughout the last two decades, as companies have kept outsourcing their operations. Nevertheless, there seems to be no related research available that would help dealing with this specific problem.

The purpose of this study is to develop a framework for selecting a suitable inventory counting approach for a dynamic production network. Specifically it means that the study aims to define the key questions of a stocktaking policy, to develop an efficient way to count inventory in practice and to measure and improve inventory record accuracy in a multi-company environment. The problems are viewed from a logistics/manufacturing standpoint, but also the accounting regulation is taken into account.

The framework is applied to the case company, and detailed recommendations for a counting approach are given in the empirical part of the study. Recommendations include ways to measure inventory accuracy and set targets, a plan for realizing counting work at external warehouses and in the main factory, as well as ways to use inventory error data to improve processes and to facilitate future investigation of errors. The results can mainly be generalized to other companies that have outsourced their manufacturing and warehousing operations, but held ownership of the stock used in these operations.

Keywords: Cycle counting, external warehouse, inventory accuracy, inventory control, physical inventory, stocktaking, 3PL, 4PL.

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Materiaalikirjanpidon tarkkuus dynaamisessa tuotantoverkostossa

– Case ABB Drives

Tiivistelmä

Varastotasojen seuranta erilaisten tuotannonohjausjärjestelmien avulla on jokapäiväistä työtä useimmissa teollisuus- ja kauppayrityksissä. Näissä organisaatioissa päivittäisten toimintojen suunnittelu riippuu pitkälti varastokirjanpidon oikeellisuudesta. Virheelliset varastotiedot voivat suuresti haitata operatiivista tuotanto- tai jakelutoimintaa. Suurimmat ongelmat tulevat esiin tavaran tilauspäätösten kautta, aiheuttaen myöhästyneitä toimituksia asiakkaille, myynnin menetyksiä, tuotantokatkoksia, viime hetken muutoksia tuotannonsuunnitteluun sekä tarpeettoman suuria tilauksia jotka sitovat rahallista pääomaa ja varastotilaa.

Ongelman haitoista ja yleisyydestä huolimatta sen merkitystä on harvoin tunnustettu kirjallisuudessa. Tässä tutkielmassa syvennytään materiaalikirjanpidon haasteisiin suuren elektroniikan valmistusyrityksen ja sen kumppaniverkoston näkökulmasta. Kaiken varastoissa olevan materiaalin omistuksesta vastaa case-yritys, jonka vastuulla on pitää lukua miljoonista yksittäisistä komponenteista ja tuotteista, jotka ovat jakaantuneet useisiin teollisuuslaitoksiin. Kuvatunlaisesta toimintaympäristöstä on tullut jatkuvasti yleisempi, kun yritykset ovat ulkoistaneet toimintojaan. Kuitenkaan aihetta ei näy olevan ennen tutkittu tästä näkökulmasta.

Tutkielman päällimmäinen tarkoitus on luoda viitekehys, jonka avulla voidaan tehdä olennaiset inventointityötä ohjaavat päätökset dynaamisessa tuotantoverkostossa. Tarkemmin sanottuna tutkielman tavoitteena on määrittää tärkeimmät inventointimenettelyyn liittyvät kysymykset, kehittää tehokas tapa varastotasojen laskemiseksi ja korjaamiseksi sekä ehdottaa keinoja varastotarkkuuden parantamiseksi tuotantoverkostossa. Aihetta tarkastellaan pääasiassa logistiikan ja tuotannon näkökulmasta, mutta myös kirjanpitosäännökset otetaan huomioon.

Tutkielman empiriaosassa viitekehystä sovelletaan case-yritykseen ja sen perusteella yritykselle annetaan yksityiskohtaiset toimintasuositukset. Suosituksiin sisältyy menettely varastotarkkuuden mittaamiseksi ja tavoitteiden asettamiseksi sekä suunnitelma inventoinnin järjestämiseksi ulkoisissa varastoissa ja päätehtaalla. Lisäksi esitellään keinoja varastotarkkuustiedon hyödyntämiseksi materiaaliprosessien ja inventointityön kehittämisessä. Suurin osa tuloksista voidaan yleistää koskemaan muitakin yrityksiä jotka ovat ulkoistaneet tuotanto- ja varastointitoimintojaan säilyttäen samalla tavaran omistuksen itsellään.

Avainsanat: Inventointi, jaksoittainen inventointi, ulkoinen varasto, varastonhallinta, varastotarkkuus, 3PL, 4PL
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1. Introduction

Inventory accuracy deals with maintaining correct inventory balances, so that inventory control decisions – mainly purchasing quantities and schedules – can be based on proper information. One might think that this shouldn't be difficult: Simply instruct employees to enter transactions right and remove discrepancies once per year by conducting a physical inventory. However many companies have to live with inaccurate inventory records, which decrease the efficiency of everyday operations. This study explains how inaccuracy arises in inventory systems and what can be done to improve material tracking and inventory accuracy. An inventory accuracy strategy is also developed for the case company, based on a general theoretical study and an analysis of the company's inventory data and operational procedures. Chapter one begins the study, introducing the subject of inventory accuracy, explaining the structure and specific research objectives and defining key concepts used.

1.1. The Importance of Maintaining Correct Inventory Records

Despite the significant investments that manufacturers and retailers have spent in automating and improving their inventory management processes, there has not been enough devotion to enhance the data input used in them. Consequently inventory records and corresponding physical inventory levels still vary too much in most companies. DeHoratius and Raman conducted a research in inventory accuracy at 37 retailer stores of a publicly held U.S. company in 2004. Of the 370 000 inventory records examined, 65 % were inaccurate. Mostly the differences were quite small, only a few units each, but with so many SKU's the error is repeated continuously and undoubtedly has a counter-productive effect on the performance of automated replenishment systems and demand forecasting systems. It is of course somewhat questionable, whether the results can be generalized to other companies, but either way the problem is one that all major retailers and manufacturers must somehow respond to.

With the help of enterprise resource planning systems, stock is monitored and measured every day in most manufacturing and retailing companies. Therefore inventory record accuracy is an important issue in a large number of organizations. Nevertheless its significance is rarely acknowledged in the literature. One of the reasons for the lack of research is probably the cultural fact that inventory control is not viewed as a management function like forecasting or material requirements planning, but a kind of routine "blue collar" activity. This assumption is partially right. Cycle counting is easy when actions and transactions match seamlessly. However, that is rarely the case in real life and even if it would be, various management-level decisions would have to be made to create a stocktaking policy. The most difficult thing is to know what to count and to coordinate the timing of the events, especially in a company with over 10'000 SKUs spread over multiple facilities.

Inventory record faultiness may have significant adverse effects on daily operations. It causes ineffective inventory order decisions, which may result in late deliveries, future lost sales, idle time for production lines, unnecessarily high holding costs or just plain waste of floor space. In companies applying the Just-In-Time – philosophy and keeping inventory levels low, inaccuracy-related problems are even more emphasized.

There are also significant accounting implications related to inventory accuracy. In the recent years corporate governance -related guidelines and legislation, as for example the Sarbanes Oxley Act in the U.S., have been passed in various countries, pushing companies to improve the accuracy of their accounting, inventory accuracy being a part of it. For a number of companies this is what ultimately forces them to develop and document their inventory control policies.

1.2. Research Problem and Objectives

Inventory accuracy is a factor that affects operational decision making and thereby the financial performance of all manufacturing and retailing companies. Especially those companies that have outsourced parts of their operations to third party logistics service providers or contract manufacturers while keeping ownership over the involved inventories face difficulties maintaining accurate inventory records. This master's thesis study aims to define the essential aspects of inventory accuracy that need to be considered. Among these are the cost effects associated with inaccurate inventory records and the means companies have for achieving higher levels of accuracy. The main research question can be phrased as following: What are the adverse effects related to inaccurate inventories and what can be done to improve the accuracy of stock records in enterprise resource planning systems?

Generic theoretical objectives related to the research question include the following: Firstly, the key decisions determining an accuracy strategy are to be identified. Secondly, a framework is to be developed for determining cycle counting policies regarding stock held at external warehouses, supplier's premises and contract manufacturers' facilities. From this point forward the term *external warehouse* refers to any materials or components owned by the principal company but physically stored outside its premises. The third theoretical objective is to gather and evaluate various definitions and measures of inventory accuracy.

Objectives for the empirical study included in this thesis include the following ones: The main objective for the empirical part is to develop an accuracy strategy for the case company. This objective is pursued by applying the theoretical findings discovered earlier in the study to the case company. Prior to applying the model and developing recommendations for the case company, its inventory accuracy must be carefully evaluated using quantitative measures. Also the cycle counting process used by the case company is to be analyzed qualitatively and suggestions are to be given for improving the process and directing cycle counting efforts more effectively. One key issue in focusing cycle counting efforts is the application of proper ABC analysis. For this purpose, the usability of various ABC classification factors presented in literature are evaluated quantitatively.

1.3. Limitations and Study Methods

In addition to theoretical publications, the study is based in conversations held with managers and workers operating in the fields of production, logistics and accounting in the case company. The empirical part of the study also relies heavily on analyzing inventory data found in the case company's ERP – system. A third source of information about the case company is formed by the case company's internal reports and work instructions.

Considering the available material and the research objectives the selected research methods are as follows:

- Review of previous theoretical findings related to inventory accuracy.
- Qualitative modeling of the theoretical framework and the case company's cycle counting process.
- Statistical analysis of inventory data and ABC classification factors in the case study.
- Quantitative analysis of the labor resource needs affected by suggested improvement proposals.

The basic limitation of the study is that cycle counting only has an auxiliary function. Production- and supply chain decisions define the operational environment for which the cycle counting process must be tailored. Therefore fundamental decisions related to warehousing, transportation, production, outsourcing and information systems are considered to be given and unchangeable.

Cycle counting policies are assessed in a general level. Guidelines are given for how to develop counting policies for different kinds of facilities and production lines, but detailed product-level or stock keeping unit-level issues are not covered.

Labor time allocation issues are assessed in a limited manner. Some departments have full-time cycle counters, while smaller departments organize cycle counting as a part of the responsibilities of certain employees. The allocation of tasks to employees is left unresolved within this context. This study aims to define a standard cycle counting process for effectively realizing counts – the labor resources are not assumed to be a constraining factor.

1.4. Research Contents and Sequence

In order to help the reader to understand the big picture of the thesis, the contents and the purpose of each chapter are briefly explained here. All subchapters are not explained in detail, but only to the extent that is needed to understand the contribution of the chapter in the larger context.

The first chapter is an introduction to the study and to the field of inventory accuracy. It includes definitions of the research problem and objectives, as well as limitations and study methods. Also the key concepts are listed and explained here.

Chapter two reviews previous literature related to inventory accuracy. Articles are roughly divided by subject and presented in a chronological order.

Chapter three builds on previous research, attempting to specify the most important decisions that should be included in an accuracy strategy. At first, several definitions are given to inventory accuracy, as well as mathematical formulas for the objective measurement of accuracy in a company. After that the financial effects of inventory accuracy are discussed, with the idea of understanding how much resources can be justifiably spent for achieving a higher level of accuracy. Chapter three also explains and evaluates the use of ABC classification of inventory for guiding accuracy efforts. Based on previous findings, the chapter ponders the usability of several possible ABC classification factors. Chapter three concludes with a list of decisions a company has to make to develop an accuracy strategy, and a framework is introduced for determining how stocktaking should be realized at external warehouses.

Chapter four includes the case description and study. At the beginning the case company is introduced and its problems are explained. Some of the accuracy measures introduced in chapter three are used for determining the accuracy level of the company's inventory records during the years 2005-2007. After analyzing the accuracy situation, the company's stocktaking process is described. Each task related to cycle counting and correcting stock levels is explained separately, as well as how cycle counting work differs in external warehouses compared to the company's main facility. Based on the process description and the implications made in chapter three, a new improved stocktaking process is introduced. An ABC classification method is also developed, based on a quantitative evaluation of the error-predicting value of some of the ABC factors. Using the strategic decisions defined in chapter three, as well as the framework that was developed, an accuracy strategy is suggested for the case company.

Chapter five concludes the study summing up the essential theoretical findings and recommendations made for the case company. The summary should give the reader a clear conception about the concrete contribution of the study.

1.5. Key Concepts

The key terminology used in the study is listed and defined here. Key concepts are assumed to contain the meaning explained in this chapter, unless otherwise mentioned.

Physical inventory	The physical counting of an entire warehouse at once, usually in one day.
Continuous physical inventory	The gradual counting of the inventory throughout the fiscal year. Every line item is counted once.
Cycle counting	The physical counting of warehouse stock and correcting inaccurate inventory balances. Some line items are counted more often than others.
Dynamic counting	Performing counts while production is running.
Inventory difference	The difference between the inventory balance record and the actual physical amount of a line item. Each item usually has two units of measure, which can be positive or negative: • Physical amount, i.e. pieces, weight, length etc. • Financial value
Routing	Automatic scheduling of production material usage in an ERP –system. Material and labor costs can be allocated to profit centers based on routings.
Apparent inventory difference	A difference which occurs when transactions do not happen simultaneously with actual material flow, e.g. when routings consume inventory balance when the material has not actually been removed from the shelf.

Production backflush	Transactions of items consumed, when their inventory record is zero or when their use has been blocked, are listed as production backflush. When their inventory record is untied again, the backflush is cleared.
External warehouse	In the context of this study, external warehouse refers to any kind of facility, where components or products owned by ABB are stored. This facility can be a 3pl or 4pl logistics service provider, a supplier or vendor, a contract manufacturer or a subsidiary (factory).
SKU (Stock Keeping Unit)	A collection of items that are identical in form, fit and function. Usually a SKU is identified by its material code.

2. Viewpoints to Inventory Accuracy

Inventory accuracy is a topic related to the field of inventory control (Heizer & Render 2004, 454), which itself deals with maintaining economic inventory levels (Krajewski & Ritzman 2005, 659-661), being a sub-topic of operations management. In the organizational context of companies, cycle counting can be viewed as part of inventory control, which is "concerned with maintaining the correct level of stock and recording its movement" (Ballard 1996, 12). Inventory control is a separate function than warehouse management, which in contrast refers to the executive level decisions of allocating and providing the necessary human and capital resources.

There is a wide variety of inventory control research available. However, a prevailing assumption of these studies is that inventory managers make their decisions based on perfect data records. Inventory errors themselves and their causes, as well as their solutions, are generally neglected or covered only in a throwaway remark. Thereby inventory accuracy is a considerably narrower and less explored field of study than inventory control in general. The following chapters review existing research related to inventory accuracy. They should serve as a cross-section of the inventory accuracy literature. Chapter 2.1 describes how researches have tried to address the inventory accuracy problem by developing different cycle counting policies. The common idea of these studies is that reaching better accuracy has a cost, which must be balanced against the potential savings and benefits. Chapter 2.2 introduces studies that approach the problem of inaccurate inventories using a method well known in the field of quality management: Statistical process control. Chapter 2.3 explains how the general problem of inaccurate data records is viewed in information systems science.

2.1. Cost-effective Cycle Counting Policies

There has been a variety of studies considering the suitability of different cycle counting policies and calculating their effects. One of the first scientific papers dealing with inventory inaccuracy, Schrady (1970) defines various record accuracy measures in the context of U.S. Navy supply operations. Iglehart & Morey (1972) considers a buffer stocking and inventory counting policy designed to address variations in demand and inventory accuracy. However, their model is not relevant in the present day, because it does not take cognizance of inventory holding costs, resulting in excessively large stocking recommendations and long cycle counting intervals. Bernard (1985) discusses the practical application of cycle counting and underlines the importance of locating and correcting errors. Morey (1985) calculates the effects that three operational improvements, i.e. increasing the frequency of cycle counts, raising buffer stock levels and eliminating sources of errors have on service levels. Flores and Whybark (1987) study the implementation of multiple criteria ABC analysis in two companies, a retailer and a manufacturer. The most significant outcome of the study was that product criticality can be accurately judged by managers who know the items well. Neeley (1987) presents two variations of cycle counting, based on modeling the deterioration of accuracy. There has also been some criticism of cycle counting: Graff (1987) states, why measuring errors does not necessarily mean eliminating them, and criticizes the use of cycle counting as a tool for controlling inventory accuracy. Sheppard & Brown (1993) study the causes of inventory record keeping errors in a manufacturing environment. Ballard (1996) illustrates viable policies for inventory monitoring and measurement, as well as recommendations for warehouse management system selection. Axäter (2000) describes the preconditions necessary for efficient inventory control and forecasting. One of these preconditions is a decent level of accuracy. Brown et al. (2001) performs a simulation to measure the effect that inaccuracy has on MRP inventory and delivery performance. Clear causality is found between accuracy problems and problems with service levels and inventory carrying costs. Dehoratius & Raman (2004) examines a large retailer's inventory accuracy across stores and identifies cause factors. Kang & Gershwin (2004) carries out a simulation of the stock loss and stockout effects caused by inventory inaccuracy and proposes various compensation methods for lost inventory with known distribution and also analyses the suitability of these methods. Dehoratius et al. (2006) presents a Bayesian demand estimation model meant for assessing inventory management problems caused by inaccurate inventory data in a retailing environment. Kök & Shang (2007) introduces a policy for optimizing cycle count intervals. A noteworthy remark is that products with higher value, higher error variance, lower inspection cost or lower demand variability should be inspected more frequently.

2.2. Applications of Statistical Sampling Methods

The application of statistical process control to inventory accuracy issues has been studied to some extent. It is an approach commonly used in the field of quality management, but its direct appliance is limited by the fact that auditing regulation in the western world provides that all items are counted at least once a year. Martin & Goodrich (1987) were among the first to apply statistical sampling to cycle counting. They introduce a method of stratified sampling based on ABC classification, for measuring overall accuracy without counting the whole inventory. Ernst et al. (1992) presents an application of control charts for measuring inventory accuracy. The paper discusses the possibility of replacing cycle counting with statistical sampling. Hart (1998) uses a control chart approach as well, but for determining the accuracy rate of an automated counting process based on bar-code scanners. Mikkola (2006) adapts the method for the needs of a petroleum retailer with automated inventory measurement for petroleum tanks.

2.3. The Perspective of Information Systems Science

Generally speaking, inaccurate data is a problem faced by the majority of organizations. In information systems science the subject is referred to as "dirty data". Kimball (1996) brings out the problem of dirty data and gives examples of the damage it causes in various industries. Wang and Strong (1996) introduces a framework for evaluating data quality from the perspective of data consumers. Strong et al. (1997) develops recommendations for information system professionals to improve data quality as perceived by data consumers. Russel & Taylor (2000, 665-662) gives a clear illustration of a typical MRP process. Although inventory errors are not discussed, the conceptualization is a useful tool for better understanding of how errors appear in MRP-systems and affect production scheduling. Kim et al. (2003) develops a classification of dirty data and describes how it arises and distorts decision making. Zipkin (2006) discusses the far-reaching possibilities of RFID technology in recording transactions and making them easier to measure. He also reminds the readers of the unsolved obstacles in RFID implementation and its drawbacks.

3. Developing an Accuracy Strategy

Chapter two was a quick overview of existing inventory accuracy literature. This chapter explores past research and builds on previous findings in the field of inventory accuracy. The supporting structure for the theoretical resoning that will be reported here mainly constitutes of previous cycle counting studies presented in chapter 2.1. The aim is to build on previous research and develop a framework for managing accuracy issues in the complex outsourcing setting there many large companies find themselves at present.

3.1. Accuracy definitions and background

There have been various definitions for inventory error (or variance), but they all resemble each other. Schrady (1970, 133) says that a stock record is in error when it is not in agreement with the actual physical situation. Almost identically Iglehart & Morey (1972, 388) state that: "an inventory stock record is in error when the stock record is not in agreement with the physical stock". A later study, Morey 1985 uses exactly the same definition. Further, according to Neeley (1987, 64), inventory variance exists when the recorded balance-on-hand differs from the physical balance, and this happens due to the continual use of items. Similarly, another definition says that the inventory record is in error when "the recorded inventory quantity of an item fails to match the quantity found in the store" (Dehoratius & Raman 2004, 1). Sheppard & Brown (1993, 45) states that "error is a construct which may be operationalized in several ways, including: categorical (error/no error), percentage error and absolute magnitude of error."
Apart from these, Schrady (1970, 135) defines residual error, i.e. the stock error that remains after record corrections. There is always the possibility of mistakes in the correction process, and therefore the error is sometimes not entirely corrected. This is a noteworthy remark, especially in a complex environment where items are spread over multiple facilities and the actual physical situation can not easily be specified.

The error can be either positive or negative. It is positive when the actual stock exceeds the record and vice versa. Both positive and negative errors can have several counter-productive operational and financial effects.

For many companies, inventory record inaccuracy is a major obstacle to achieve operational excellence (Kök & Shang 2007, 185). Its financial and operational effects, as well as its emergence, will be discussed later in this study. In any case, if record inaccuracy is a problem for many companies, what are the available means for improving it? DeHoratius & et al. (2006, 2) group the approaches into three generic classes:

- Prevention
- Correction
- Integration (adjust to errors)

Prevention means all the efforts taken for ensuring that transactions equate real-world actions in the first place. It includes the design of transaction processes and training of personnel to ensure that transactions are performed correctly. It also includes inspection of material quantities before manually entering them. As a part of prevention work, knowledge about previous errors can be used to identify relevant problems and remove their root causes or minimize their effect (Bernard 1985, 30, Latham & Williams 2003, 10).

Correction basically refers to the counting and correcting of stock records, that traditionally has been the purpose of physical inventories. Correction is the fundamental routine that is needed for achieving higher levels of accuracy (Bernard 1985, 27, Kök & Shang 2007, 185, Graff 1987, 39). Since the eighties cycle counting has been evolved as an alternative to annual physical inventories, which were required by external auditors (Graff 1987, 39). In its simplest form, cycle counting is just counting and correcting stocks, but when applied thoroughly, it is meant to include all three classes of accuracy efforts, especially prevention of future errors.

Integration is adaptation to inaccuracy, which means performing operations in ways that take inaccuracy into account and eliminate its effect. Basically this is everyday life in companies, where people do not trust inventory data but have to live with it. Usually it means checking the inventory situation before making any decisions based on it (e.g. production schedules or purchases) or simply carrying buffer stocks. Buffer stocks are not originally meant to protect against inventory errors, but still help to prevent out-of-stock situations caused by them (Morey 1985, 412). One way to cope with errors that could be useful in automated replenishment systems is to measure the distribution of the error and build it in the replenishment calculations. Such methodology has been proven to work in mathematical models (Kang & Gerschwin 2005, 855, Dehoratius et al. 2006, 30). Nevertheless so far it has only been a theoretical approach. Implementation of such models would require a lot of measuring, computational skills and trust, not to forget the profound mathematical understanding needed for designing such models. However, as perpetual inventory records and automated replenishment systems are evolving day by day, it would not be unthinkable to see such a system in use someday in the future.

Regarding the three ways to protect against inaccuracy (prevention, correction and integration), Morey (1985, 416) sums up the most commonly used ones by companies: "More buffer stock, more physical inventories, more corrective action to eliminate or reduce the causes for the errors." Of these three, increased buffer stocks and aggressive cycle counting efforts are the easiest to implement in a constant basis, meanwhile actual correction of the root causes is often neglected by companies, despite being necessary for preventing the same mistakes from happening again. Hence the main barrier for successful cycle counting implementation is "the absence of a dedicated focus on finding and fixing the causes of errors" (Latham et al. 2003, 12). Therefore if a company wants to avoid this obvious pitfall, errors should be reported in an organized manner and responsibility for their correction should be defined clearly. Unless this is done, the cycle counters are left alone with the responsibility for finding and correcting errors, while the rest of the employees lose their sense of accountability. In such case, failure is virtually guaranteed (Graff 1987, 41).

3.2. Quantifying Accuracy and its Financial Effects

The main objective of this study is to develop a suitable cycle counting policy. For this purpose, this chapter builds on previous cycle counting literature, trying to find the essential success factors that determine a counting policy. Basically cycle counting means that some items are counted more often than others. However for the context of this study, a cycle counting policy is defined as a strategy for determining all accuracy measures applied in a company: prevention, correction and integration. Furthermore, the concept of cycle counting is extended to cover also continuous physical inventories. After all, it is just a special case when all items are counted only once in a year. This might be a relevant strategy in some situations when the extra work of correcting inventory balances more than once per year is regarded unnecessary.

According to Piasecki (2003, 82), the ultimate goal of cycle counting is "to achieve excellence in customer service and optimize the effectiveness of internal operations." Specific objectives are identifying process problems and correcting on-hand balances (Piasecki 2003, 82). The basic idea of cycle counting in practice is that based on financial importance and sometimes other factors as well, stock is divided in three classes: A, B and C. The A items are counted more often and more carefully than the B items and so forth. This method called ABC classification can be used for other purposes than cycle counting as well. According to Heizer & Render (2004, 454), policies that may be based on ABC analysis include the following:

- Purchasing resources allocated to bidding and supplier development should be higher for A-items.
- A-items should have tighter inventory control (including cycle counting).
- Forecasting should be planned more carefully for A-items

3.2.1. Measuring accuracy

Like all focused activities performed in a company, inventory accuracy efforts require a specified set of targets. Without targets it is impossible to say if the operations are performed successfully. Setting targets for physical inventories / cycle counting depends on two perspectives: Operations management (logistics and production) and accounting. Accounting (here: external accounting) is only concerned with the correction of inventory records, because the purpose of inventory accounting is to give a good and accurate picture of the company's stock situation and how the cost of goods is spread over the accounting periods (Wild et al. 2007, 202). Operations management in contrast looks at frequency and magnitude of individual errors, trying to minimize them.

The most commonly used measures of inventory accuracy in theory and practice are:

- Erroneous SKUs per total SKUs (e.g. Dehoratius & Raman 2004, 13, Piasecki 2003, 152, Brown et al. 2001, 48, Neeley 1987, 64). This is an operational measure, in contrast to the latter that is needed for accounting purposes.
- Total financial inventory error (needed for correcting current assets in financial statements).

Researcher's recommendations of inventory accuracy targets (erroneous per total SKUs) vary between 90 and 99+ % (Brown et al. 2001, 48). In addition to these targets, research has been made of accuracy figures across industries. Piasecki (2003, 174-177) introduced typical environment-specific accuracy figures for use as rough guidelines. Across industries these figures vary between 50 and 100 percent, with 88 % to 98 % being the range for manufacturing environments when using 2 % tolerance limits (error divided by book quantity). Basically, setting the target is a question of balance between two cost factors. One is the accuracy input, which is the cost of performing counts and correcting and reporting errors. The second is the inaccuracy expense. The optimization of these costs will be discussed later in this chapter.

In addition to the above mentioned measures of inventory accuracy, there are several others. If only the proportion of erroneous SKUs is used (which is surely easy and informative), the magnitude and financial effect of errors are neglected. The other useful measures include:

- Total financial inventory error, divided by warehouse stock (current assets), sales or number of SKUs
- Seriousness of error (error divided by stock record)

Proportioning the cumulative financial error in relation to common business figures is a good way to evaluate how accuracy has evolved in changing business conditions. For example if sales, product selection, and value of stocks have all grown, it is expected that the financial error grows at the same proportion. If it remains the same, relative accuracy has actually improved.

The measure of seriousness of error means that the physical magnitude of the error is compared to what the stock quantity should have been (Schrady 1970, 139). For instance if the record shows an on-hand balance of 15 pieces of which 13 are missing, it is a riskier situation for operations than when the same amount would be missing out of a recorded stock level of 100 pieces. The same measure can be extended for the evaluation of overall accuracy in a company. This measure is called *the on-hand weighted error percentage* and it can be calculated as following (Schrady 1970, 139):

If a_i = actual stock level of item i

and r_i = recorded stock level of item i,

$$\textit{The On-hand weighted error percentage} = 100\left[\frac{1}{N}\sum \Delta_i / m_i\right],$$

where $\Delta_i = |a_i - r_i|$

and $m_i = \max(a_i, r_i)$.

Formula 1 On-hand weighted error percentage.

The on-hand weighted error percentage is an indicator of how meaningful the errors are in comparison to what the stock level should have been. It gives a good understanding of how operations may be affected by the errors. The downside of this measure is that the stock level is a constantly changing parameter, so for an individual SKU the measure depends on the time when the item is counted. However in the long run measurement becomes even, as thousands of items are counted throughout the year.

Apart from the above-mentioned measures, the following formulas give a picture of overall accuracy (adapted from Piasecki 2003, 154-156):

$$1.\ \text{Net piece accuracy} = \frac{(\text{sum of pieces on hand - sum of piece variances})}{\text{sum of pieces on hand}}$$

$$2.\ \text{Net financial accuracy} = \frac{(\text{total value of stock - total value of variances})}{\text{total value of stock}}$$

$$3.\ \text{Absolute piece accuracy} = \frac{(\text{sum of pieces on hand - sum of absolute piece variances})}{\text{sum of pieces on hand}}$$

$$4.\ \text{Absolute financial accuracy} = \frac{(\text{total value of stock - total value of absolute variances})}{\text{total value of stock}}$$

Formulas 2, 3, 4 and 5 Accuracy measures (Piasecki 2003, 154-156).

Of the above formulas, the two net measures serve accounting better than operations, because negative and positive errors balance each other. In contrast the two absolute figures give a better picture of how operations are affected, as both negative and positive errors have a negative cost effect, as discussed in chapter 3.2.2.

The fastest way to evaluate the overall accuracy of an inventory system would be to apply statistical sampling and count only a small part of the inventory. Similar to quality control methods used to measure production processes, theorists have introduced control charts and sampling techniques for measuring inventory accuracy (Martin & Goodrich 1987, 24-27, Ernst et al. 1992, 33-36, Hart 1998, 44-47). According to one study, sampling SKUs based on similar variance results in significant savings in counting time (Martin & Goodrich 1987, 27). The idea is to group the SKUs based on book value and select equally sized samples from these groups. The method might be useful if the only purpose was to measure accuracy. However, measuring overall accuracy does not help to correct error causes or guide improvement efforts. Moreover, Finnish accounting legislation requires all items to be counted at least once in a year and sampling can not replace this duty. In conclusion, statistical sampling can be used to complement physical inventories or cycle counting, but as a standalone method it would not provide sufficient information.

3.2.2. Balancing accuracy expenses

There have been several attempts of determining the level of stock record error economical to achieve and maintain. Probably the first quantitative modeling attempt was Iglehart & Morey (1972, 388-394). The study aimed to develop a rationale for determining "the level of stock record error economical to achieve and maintain." However they neglected the existence of holding costs, and thus recommend keeping excessively large inventories and performing cycle counts at very long intervals, what would probably not be feasible in most of today's organizations. There has not been a concluding answer for determining how many times the stock should be counted, basically the only thing sure is that the more errors there are, the more often the stock should be counted and stock records corrected. To put it in a nutshell, it is a tradeoff between accuracy and inspection cost (Schrady 1970, 141). If the inspection cost is high, it "may be better to inspect less frequently but carry more stock to account for uncertainty" (Kök & Shang 2007, 186). However, this is a rather simplistic view of reality and accuracy may mean various things to companies, depending on business needs. In order to determine how inaccuracy affects operations and what the related expenses are for a determined company, one must asses it more carefully in a detailed manner.

Of all the negative effects caused by inaccuracy, unknown stock loss is perhaps the most imminent. Stock loss can be categorized into known and unknown (Kang & Gershwin 2005, 845), from which the latter is caused by negative inventory variance. This happens when all material usage is not registered in the inventory system (e.g. normal usage, scrapping or theft), or when stock is physically lost in a production facility or warehouse and becomes inaccessible inventory. Inaccessible inventory refers to products that are somewhere in the facility but are not available because they can not be found, and must eventually be deducted from the on-hand items balance. (Kang & Gershwin 2005, 845). The total financial stock loss, i.e. the total negative variance of current assets has a direct effect on the company's bottom line, and is measured routinely in all companies because of accounting legislation.

Besides the imminent financial effect of stock loss, errors have numerous operational effects that harm organizations in their daily routines and decrease efficiency. As Morey (1985, 412) says, "the primary impact of these (inventory record) errors is … unplanned stockouts." Moreover, inaccuracy may result in less measurable but equally important disadvantages, i.e. poor customer service, unpaid receivables and lack of trust in the computer system data (Stratman 2005, 28). According to a simulation study, frequency, magnitude and location (comp/semi/fini) of errors affect yield (or service level) and holding costs (Brown et al. 2001, 48). Here the frequency refers to the proportion of erroneous SKUs, the magnitude is the absolute size of the error and the location tells whether the erroneous SKU is a component, a semi-finished- or a finished product. The location can also be defined as the three basic types of inventory: Raw materials and components, work in progress and finished goods (Ballard 1996, 12). The closer the SKU is to the end of the production process, i.e. the more nearly finished it is, the more it affects holding costs and shipments to customers (Brown et al. 2001, 56).

The counter-productive effect of stock loss is greater in lean environments and companies using automated replenishment systems (Kang & Gershwin 2005, 843). In automated replenishment systems, even a small rate of stock loss can create severe out-of-stock situations, if it is not corrected in time. This notion can also be turned the other way around: if stock records would be accurate, replenishment could be automated and labor hours saved where replenishment orders are currently performed manually. As well as the company in question, inventory accuracy may also affect its suppliers' production planning, at least if suppliers have access to the buyer's inventory data and use it for planning purposes (DeHoratius & Raman 2004, 3).

The following (table 3-1) is a checklist for estimating the true costs of inaccuracy. Most of these cost elements are at least difficult to count and not usually monitored in the majority of companies. However, experienced operations managers usually have some idea of these cost elements and their magnitude. The estimations listed in the cost potential-column of table 3-1 are based on the average of multiple rough guesses made by managers in the case company, as well as the author's view. With the help of this checklist it should be possible to make a rough estimation of the total inaccuracy expense for an individual company, thus gaining understanding of how much it is wise to invest in improving accuracy.

Cost element	Explanation	Cost potential
Shipping errors.	Wrong quantity of items shipped to a customer. Causes extra handling- and compensation costs.	100s to 1 000s
Missed shipments.	Number of times when an unexpected shortage causes delays to shipments.	**100s to 100 000s**
Production interruptions.	Number of times when a production demand can not be met because of unexpected shortages.	**1 000s to 100 000s**
Production schedule changes.	Last minute changes to production- and workforce schedules.	1 000s to 10 000s
Expediting or de-expediting.	Delivery date changes that result from inventory record corrections.	100s to 1 000s
Extra holding costs.	Money tied to unnecessary purchases and inaccessible inventory, as well as safety stock to compensate for inaccuracy.	**10 000s to 100 000s**
Vendor payment problems.	Uncompleted material receptions prevent bills from being paid in time. This may result in loss of discounts or problems with future deliveries.	100s to 10 000s
Labor hours spent searching for lost inventory.	Wasted labor time in the picking process.	1000s to 10 000s
Inspection and correction costs.	Any time spent in checking and correcting the quantity of an item during daily operations.	**10 000s to 100 000s**

Table 3-1 Inaccuracy costs, adapted from Piasecki 2003, p 169-170. Color codes indicate the relevance of the cost: Green = small, orange = meaningful, red = remarkable.

The figures in the cost potential column in table 3-1 are universal year-level estimations for companies of the same size category as the case company, i.e. with sales counted in hundreds of million euros, a workforce of several thousand employees and an average stock level of several million euros. The inaccuracy expense might easily rise to hundreds of thousands, which is generally considered as financially meaningful. However it is not necessarily a large sum compared to sales. For example an accuracy cost of 0,5 million euros from a sales revenue of 500 million euros is only 0,1 % of sales. Many companies can therefore afford a lower accuracy level. However if a company has low profit margins, improving inventory accuracy can be a good way of cutting costs, especially if there are problems with material processes.

Concluding the discussion over the operational and financial effects of inventory record inaccuracy, one could say that the yearly expense can easily rise to a total of several hundred thousand euros. To determine the economical level of accuracy would thus be to balance all the listed costs against the cost of improving accuracy, i.e. cycle counting efforts, error source investigation and transaction process improvements.

One way to control the cost of accuracy efforts would be to measure the efficiency of cycle counting work, that is how many SKUs can be counted with the designated resources. A natural measure of performance is a productivity ratio, the ratio of outputs to inputs (Coelli 2005, 1). In this case the number of counted SKUs is the output, while the input could be for example the total work hours spent or the total cost of work hours spent. Thus the useful measures of cycle counting efficiency would be:

- Cost of counting work / number of counted SKUs
- Work hours spent / number of counted SKUs

These measures indicate how fast items can be counted. It is though important to make the notion that they shouldn't be used as a basis for motivational compensation of the cycle counting clerks. This is because the efficiency of cycle counts is largely determined by the quality of material flow transactions made in the production chain – not to mention how ineffective it would be to maintain a compensation system for only a couple of full-time employees. An individual cycle counting employee has very limited influence over the productivity of his/her work, whereas production and logistics managers have the responsibility of improving material management systems and making them more error-proof, thus facilitating the correction of inventory balances. Thereby the above efficiency measures are better suited for measuring how easy and fast it is to count and correct inventory records, and so give an understanding of how well material management works.

Whatever the desired accuracy level would be, it is essential to notice that simply counting items and correcting inventory records does not remove the root causes of the problem. In fact production and logistics managers should understand the fundamental assumption that cycle counting is treating the symptom rather than the problem (Kuipers et al. 2004, 18). If a company truly wants to improve its operations, it should use the stocktaking information to systematically locate and remove errors from transaction processes. A common mistake leading to the failure of many cycle counting programs is "viewing the cycle count as a report card rather than a tool that triggers improvement efforts" (Latham et al. 2004, 12).

3.3. Evaluating ABC Criteria Based on Error Appearance

The basic idea of cycle counting is that based on financial importance and sometimes other factors as well, stock is divided in three classes; A, B and C. For this purpose the analysis requires a set of factors for ranking the inventory items. Traditionally ABC classes have been set based on one single figure, the *annual financial volume,* which is obtained by multiplying the annual demand of an item with its cost (Flores & Whybark 1987, 79, Heizer & Render 2004, 453, Krajewski & Ritzman 2005, 666). This is the standard straightforward way to deal with ABC analysis, but if the objective is to use the ABC classification for guiding operational efforts, additional criteria should be used (Flores & Whybark 1987, 79). There are various possibilities available. Selection of ABC factors is basically about choosing one or more parameters whereby the items are ranked into ABC classes. When determining the factors, one must first think what kind of items should be counted more frequently. As was discussed in the previous chapter, cycle counting is about balancing the costs of inaccuracy to the cost of accuracy efforts. From this assumption, it is relatively easy to derive the characteristics of suitable ABC criteria. Items that are more prone to significant errors (financially or operationally) and which are easier to count should be inspected more frequently. It is though not simple to determine which items are prone to errors or which errors are critical. The first step would be to analyze the types of errors and their consequences. This kind of statistics can be obtained by recording error types as a part of cycle counting work. Each company likely has its own set of typical errors, depending on operational characteristics, but there are also a lot of similarities between organizations. Various researchers have published lists that illustrate typical errors emerging in production and/or retailing environments. Table 3-2 shows a synthesis of error and root cause lists that have appeared in research publications.

Function	**Detailed error**	**Root cause**
Cycle counting	Component substitutions	Carelessness
Order picking	Data input errors	Lack of focus
Production reporting	Entering a transaction twice	Lack of knowledge
Put away	Filling the wrong field in a form	Lack of transaction discipline
Receiving	Forgetting to enter a transaction	Poor document control
Forwarding	Incorrect computer logic	Poor forms design
	Incorrect transaction timing	Poor process design
	Lost paperwork or pallet markings	Task Interruptions
	Missed field in a form	
	Picking errors	
	Shipment / reception errors	
	Theft	
	Transaction error	
	Unidentified	
	Unit of measure	
	Unreported scrap or returns	
	Wrong item	
	Wrong location information	
	Wrong quantity	

Table 3-2 Synthesis of error cause lists (Kang & Gershwin 2005, 844-845, Bernard 1985, 27-29, Piasecki 2003, 1-20, Iglehart & Morey 1972, 388, Morey 1985, 411, Latham 2003, 12, Latham et al. 2004, 13).

As can be seen in the left column of table 3-2, transaction errors leading to record inaccuracy happen in all the basic operational task areas found in a production environment. If we look into the detailed error cause (middle column) we see that there is a wide spectrum of error possibilities, which varies largely from one company or department to another. Therefore it is not useful to develop a very detailed error reporting process. Too much detail just makes improvement efforts overcomplicated. What we are interested in is the root cause of the error: Is it carelessness, lack of focus or lack of knowledge of an individual employee, i.e. something that should be addressed with motivation or training or is the root cause a faulty or inadequate transaction process, i.e. a systematic error that requires process adjustments. By collecting information about the root causes of errors and their relative importance, a company can learn how to allocate improvement resources wisely (Latham 2003, 12).

After the most significant causes of errors have been identified it is possible to start evaluating which ABC criteria could best represent common predictors of errors. Theorists have introduced various ABC factors, which are summarized in Table 3-3:

ABC factor	**Research Appearance**
Transaction activity	Neeley 1987, Bernard 1985, Sheppard & Brown 1993
Dollar usage	DeHoratius & Raman 2004, Sheppard & Brown 1993, Kök & Shang 2007
Criticality to operations	Bernard 1985, Sheppard & Brown 1993, Kök & Shang 2007, Flores & Whybark 1987
Error history	Bernard 1985
SKU commonality	Bernard 1985, Sheppard & Brown 1993, Kök & Shang 2007
Inspection cost	Kök & Shang 2007
Demand variability	Kök & Shang 2007

Table 3-3 ABC factors in existing research.

The advantages and drawbacks of the listed ABC factors are discussed in this section. The first factor listed in the table, transaction activity, can be defined as "the number of transactions against a given SKU per some time period" (Neeley 1987, 64). The idea of using transaction activity as an ABC factor is based on the assumption that every time a material moves there is a possibility for a mistake (Bernard 1985, 30). According to Sheppard & Brown, probability theory suggests that the more transactions there are, the higher the probability for errors becomes. However, the same research concluded in the counterintuitive result that the number of transactions does not correlate significantly with errors (Sheppard & Brown 1993, 48). The authors of the study give a rational explanation for their finding: If errors are random with a zero mean, the positive and negative errors outweigh each other, resulting in a zero outcome after a given time interval with sufficient positive and negative errors. Applying reverse reasoning another explanation could be that transaction activity is a good predictor for systematic errors, i.e. errors with a nonzero mean. Nonetheless it is of course possible that transaction activity simply does not predict error appearance.

Whatever the predicting ability of transaction activity, it is good to note that part of the information added by the transaction activity factor is already obtained from the financial usage figure; the items that total most of the money are often the same that have the highest activity rate. Therefore the addition of this factor to the analysis is somewhat questionable.

Criticality is a factor that is easy to understand but hard to determine objectively. Criticality may refer to the importance of a stock keeping unit or to the severity of the error, depending on the context. The basic idea is that some errors may cause problems like production interruptions while some do not. It is though hard to use criticality as a basis for ABC classification, because almost any item needed to build a product can cause a delay when missing. From the perspective of sourcing, critical items could be those with a long lead time, limited supply sources or items that can not be replaced with substitutes (Flores & Whybark 1987, 79). The precise meaning of criticality varies depending on the context. When talking about an individual error that has already been measured, seriousness can be measured mathematically as the error (number of pieces) divided by the recorded- or actual on-hand quantity (Schrady 1970, 139). It has been suggested that error tolerance levels should be set based on ABC, so that in class C small errors would be ignored when calculating overall accuracy, whereas in class A tolerance limits should be tighter. According to Bernard (1985, 29) a cycle counting policy should sometimes accept a certain percentage of discrepancy depending on item class.

By keeping track of the seriousness of individual errors (compared to expected stock) a person doing cycle counting could have some understanding of the criticality of those errors. The measure could be used to determine where to concentrate root cause investigation efforts or data from past errors could even be used to update ABC classes for sequencing counts in the future.

An empirical study, Sheppard & Brown (1993, 48), states that operations managers and employees can accurately define items that are most prone to errors. Based on routine experience they have a good feeling of problem SKUs, and the study shows that a difficulty rating figure that was set intuitively by a team of stockroom staff is a significant predictor of error probability. It confirms previous findings (Flores & Whybark, 1987, 85) proposing that operations managers may have a good understanding of even a relatively large selection of SKUs and their criticality being thus able to assign effectively ABC classes based on personal judgment.

Bernard (1985, 30) proposes error history as a bases for sequencing counts. The idea is that items with a lot of errors in the past have a higher error probability in the future. The thought seems reasonable, but there has not yet been any research evidence supporting it. A numerical study (Kök & Shang 2007, 203) supports the assumption in a sense by noticing that items with higher error variance should be inspected more frequently. The predicting validity of past error data probably depends on the root cause of the error. If the root cause is a systematic process failure which is not fixed when the error is detected; the same error will likely occur again. Whereas if the error in question is purely random, e.g. a single mistake made by an employee, there should be no significant correlation between past and future errors.

One attribute that has clearly been shown to be a predictor of errors is item commonality. Components used in several different products tend to be more prone to errors (Sheppard & Brown 1993, 48). This happens because when an item is used in more places, record keeping for that item becomes more complex and the number of transactions increases.

Inspection cost refers to the cost of counting an item. As it is hardly calculated in real-life companies, it remains more of a theoretical setting. In a numerical study (Kök & Shang 2007, 203) it was found that items with a lower inspection cost should be counted more often. So as to take advantage of the result in practice, inspection cost could be translated as the relative easiness to count an item. After all, the cost to count an item depends on the time and effort it takes, which again depends on how easy the inspection is in practice. Then again easiness to count is not something that could be measured quantitatively, unless cycle counting clerks would measure the time needed to count an individual line item. However the time needed varies a lot. When there is no deviation in the stock level or other obstacles requiring investigation, cycle counting work is faster than when an error is found. Inspection cost, when defined as the easiness of counting an item, is something that the cycle counting personnel could probably best assess by personal experience.

Demand variability is something that affects operations in many ways. Variance may be caused by almost an infinite number of reasons, ranging from customer behavior and market characteristics to product life cycle issues. One element that affects demand variability is whether the item in question is a commonality component. Common use components tend to have more volatile demand (Kök & Shang 2007, 203). Additionally product customization is a matter that increases demand variability under certain components. When a part of the material requirements of a product is order-dependent, it is obvious that some components will have an unpredictable demand. Based on their numerical study, Kök & Shang (2007, 203) recommend that items with lower demand variability should be inspected more frequently, but they do not explain why. One reason might be that in a situation with fast growing demand it is more important to concentrate on fulfilling the demand without wasting efforts on fine-tuning operational efficiency. In this case the easiest way is to keep high buffer stocks and accept some errors as a cost of growth and learning.

An essential characteristic in this study is the fact that some items might be stored at external warehouses, so that material owned by one company might be located at the premises of a 3pl / 4pl company or of a contract manufacturer. This is a setting that adds complication to material management, but is becoming increasingly popular as companies keep outsourcing parts of their production and warehouse operations. Nevertheless, inventory accuracy in such circumstances is a subject that has been completely ignored in the literature. Noteworthy considerations in production networks might be at least:

- Warehouse transfers – Material movement transactions between facilities increase potential for errors.

- Communication – Investigating stock record discrepancies at the principal company takes more time, because the partner company must be contacted in case of erroneous warehouse transfers.
- Training – The partner company might not have adequate people for the cycle counting task nor an incentive to train them.
- IT-system investments – Companies might have differing IT-systems, but the partner is not necessarily interested in developing corresponding systems.
- Process and policy improvements – The principal company has no direct power to decide how for example transaction processes should be developed.

Considering the issues possibly affiliated with external warehouses it would be interesting to know whether the fact that an item is stored at multiple locations has any predicting value on inventory errors, i.e. could it be used as an ABC factor.

Eventually selecting ABC factors, no matter how it is performed, should be company-specific. With today's ERP-systems it is often possible to analyze historical error data and factors affecting it. After a proper correlation analysis it should be possible to determine whether a factor has anything to do with future errors or not.

3.4. Toward an up-to-date cycle counting model

Chapters 3.1. to 3.3. discussed existing inventory accuracy research exploring questions and answers related to the selection of a cycle counting policy. This chapter builds on previous findings and gathers together the essential aspects of a cycle counting policy.

Analyze and measure current accuracy and preferably the problems and costs caused by the lack of it. The items causing the most errors should be counted more frequently, because it would help to find errors sooner. The sooner an irregularity is detected, the easier it is to investigate and find its root cause. Performing cycle counts more often would also mean reconciling inventory balances more often, which would keep overall accuracy higher.

Select ABC factors. The importance of each of the following factors should be assessed when selecting ABC classification criteria:

- Material with high turnover and value
- Commonality components
- Material stored at external warehouses
- Transaction activity
- Criticality to operations
- Error history
- Easiness to count
- Demand variability

Set classes. How large should the classes be? For instance the division could be one of the following:

1. A 10 %, B 20 % and C 70 %.
2. A 15 %, B 25 % and C 60 %.
3. A 20 %, B 30 % and C 50 %.

The figures are examples based on the case study described in chapter 4. Setting items to classes is always subjective (Silver et al 1998, 34–35) and depends on the firm's needs and operational circumstances.

Define cycle intervals. The number of yearly counts for A –items can be anything between 12 (Latham & Williams 2003, 11) and 1, which is the minimum set by legislation. Count intervals for classes B and C are set subsequently. It should be taken into account that SKUs with more errors may be counted more often regardless of the ABC policy, as purchasers and warehouse staff request balance corrections. It should also be remembered that

Select between dynamic- and off-hour counting. Is it possible to perform cycle counts while material is constantly moving? Would it be more suitable to count on evenings and weekends? Theory suggests that counting should be performed during off-hours (Silver et al 1998, 65) and there is no previous research dealing with dynamic counting. At this point of the study it is assumed that the main difference between the two methods is that off-hour counting is better planned in advance than dynamic counting work. This assumption is based on the case company's practice of using off-hour counting only for special occasions, as for counting production lines with short lead-times (actual inventory levels constantly changing) or for counting external warehouses' stock. These special occasions always need more planning, as employees have to be assigned to work outside regular working hours and the time available for the counting endeavor is limited. Planning off-hour counts will be discussed in detail in chapter 4.3.2.

Develop error investigation methods. It is possible to find and correct erroneous transactions only if transactions are clearly defined (citation needed). Only when standards are set, it is possible for an experienced employee to detect abnormalities. As ERP-systems vary from one company to another, also transaction policies vary and it is not possible to give investigation guidelines that would be universally sound and practical. One question related to error investigation is common to all companies; that is specifying when the errors should be recorded; Before or after investigation? There are at least three options for doing this:

- Investigate before entering inventory balance, i.e. enter only "real" errors. This method is used at Drives, when an error appears to be so high that it should be investigated.
- Enter count results right away, investigate later. This method gives the most ruthless picture of errors. However, a large part of the errors would be removed after investigation thus causing back and forth swings in inventory levels. Therefore it is not purposeful to enter errors in the ERP-system before they are investigated (Piasecki 2003, 117).

- Do not investigate – enter errors as they appear. This method is useful for smaller errors, which are not worth investigating. There is no point wasting resources investigating a few euros' discrepancies.

Error cause reporting: The essential questions related to reporting decisions include:

- What is the tolerance for errors, i.e. how big an inventory difference is investigated and what is the limit for reporting errors to cost responsibles?
- How accuracy problems are communicated further to the people affecting them (root cause)?

Assess the need for customizing counting policies for different departments or product families. Issues to consider might include for example:

- Departments – Smaller departments do not employ full-time counters. Cycle counting work may have to be scheduled for weekends.
- Product families – Some product families are manufactured in modules, while others have more customized work. Module production is significantly more standardized, and therefore it should be possible to remove common mistakes and make the operations more effective.

A policy for performing cycle counts at external warehouses should be thought separately. The following questions are characteristic to external warehouses:

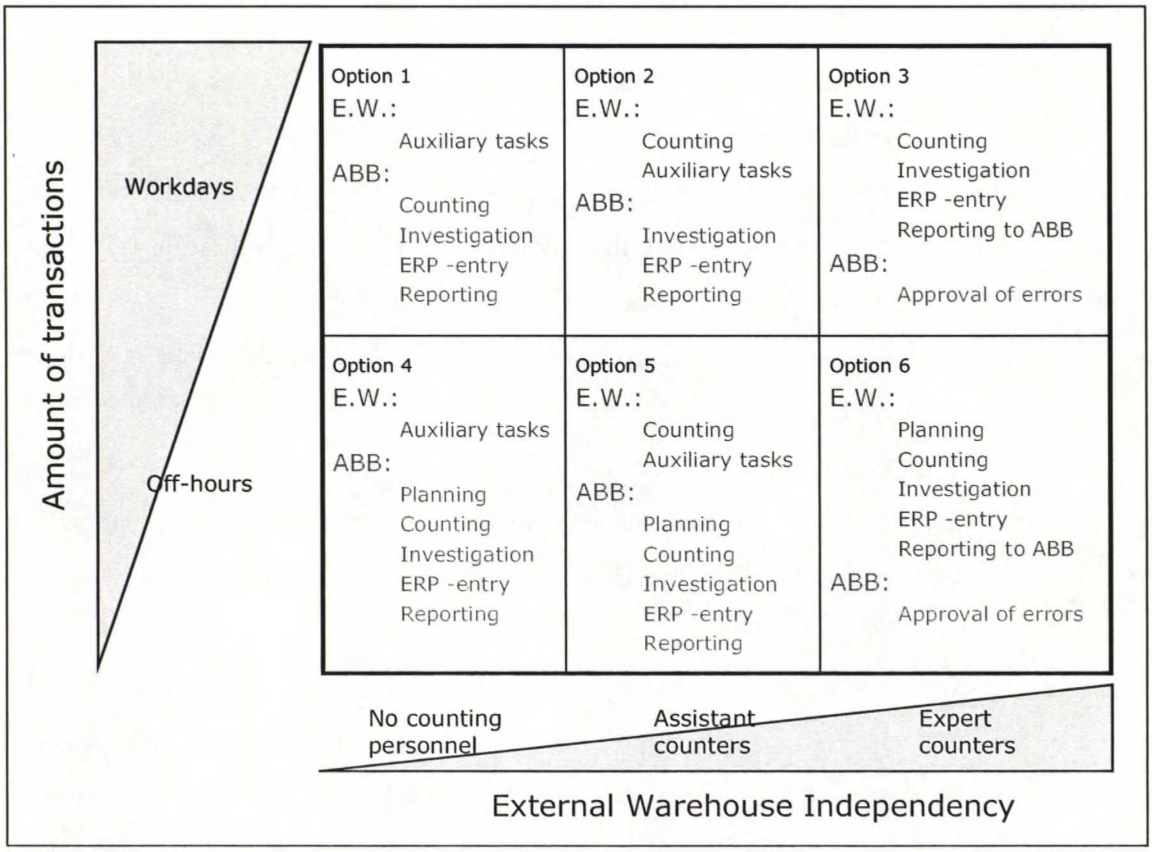
- Define responsibilities: Which tasks should be performed by the external warehouse operator and which by the principal company owning the stock.
- Count by item / count by facility: Should items in external warehouses be counted simultaneously with items counted at the factory or would it be better to count them by an independent schedule? An assumption here is that sequencing counts by item works when warehouse transfers are made correctly. If not, it is inevitable to check various facilities to correct the error.

The following table collects the decisions involved in the creation of a cycle counting policy and how much they have been discussed in previous theoretical and managerial articles (table 3-4). Details about previous literature can be found in appendix 1.

Cycle Counting Decisions		**Previous discussion** (theoretical and managerial)
General Decisions	Measure accuracy and set targets.	Medium (6)
	Define cycle intervals.	Medium (5)
	Select ABC factors and set items to classes.	High (12)
	Select between dynamic / off-hour counting method for individual production lines.	Low (1)
	Define error investigation and reporting methods.	Medium (5)
External Warehouse Decisions	Select between dynamic / off-hour counting method for each facility.	None (0)
	Define how responsibility for cycle counting tasks is shared between companies.	None (0)
	Count by item / count by facility.	None (0)

Table 3-4 Cycle counting decisions.

Picture 3-1 is a framework designed to help when selecting a cycle counting policy for external warehouses. The framework is called the EWCO –model, an abbreviation from *External Warehouse Counting Options.* The X-axis represents the independency of the external warehouse in realizing counts, i.e. how much responsibility the partner firm takes or more exactly how many of the related tasks it operates. The Y-axis represents dynamic- / off-hour counting. Basically there are only two options, counting during normal working hours and counting during quiet- or off-hours. The main difference is that these "weekend counts" require planning in advance. Each of the six options represents the division of tasks related to cycle counting. These tasks are explained in detail in chapter 4, as part of the description of the current cycle counting process.



Picture 3-1 The EWCO -model (External Warehouse Counting Options).

Explanations for the various elements of the model are listed below:

Upper row	Dynamic counting. Production is running, so actions and transactions take place continuously while cycle counting is performed.
Lower row	Off-hour counting. This is the traditional way to perform counts. Production is at its lowest and so are the actions and transactions too.
Columns	Degree of external warehouse stocktaking independency, i.e. which tasks are performed by local employees.
E.W. (green)	List of tasks performed by employees of the external warehouse in each option.
Owner (red)	Tasks performed by the principal company's stocktaking personnel

Auxiliary tasks	Forklift drivers and operators of automated warehouse equipment, factory guides, IT assistants.
Counting	Basic cycle counting work, i.e. tracking physical locations, counting and writing down amounts.
Investigation	ERP-investigation: The tracking of errors and determining the "real" amount of physical stock that should be found at a given facility. Requires much more experience than basic counting work.
ERP-entry	The recording of actual stock amounts in the ERP-system. This is a routine clerk task.
Reporting	Reporting of errors to persons liable for costs.
Planning	The planning of off-hour counts. These counts must be planned in advance, so that the limited time is utilized in the best possible way.

As there are no previous studies about cycle counting strategies in production networks, the model is based on the case company's experience. The following issues determine how demanding it is to perform counts in a given plant: Plant type, production process characteristics, number of SKUs, warehouse size (value and amount of materials), congruence of information systems and travel time from the main factory. These factors are discussed in more detail in chapter 4.3, along with the planning procedure of external warehouse counts. The assumption here is that these same factors that determine the difficulty of counting should be used to select between cycle counting options for individual warehouses.

4. Case ABB Drives – Growth Brings Complexity

The case company is a Finnish subsidiary of the global ABB group. ABB group's headquarters are situated in Switzerland and the corporation is enlisted in the New York Stock Exchange among other markets. The fundamental rules for stocktaking at ABB are set by the Sarbanes-Oxley Act 404 (SOX 404), which is followed throughout the whole ABB group, including the case company. The named regulation is mandatory for all public companies enlisted in the U.S., and it includes specific rules that control accounting practices at different company functions, stocktaking being one of these. SOX –requirements for stocktaking include:

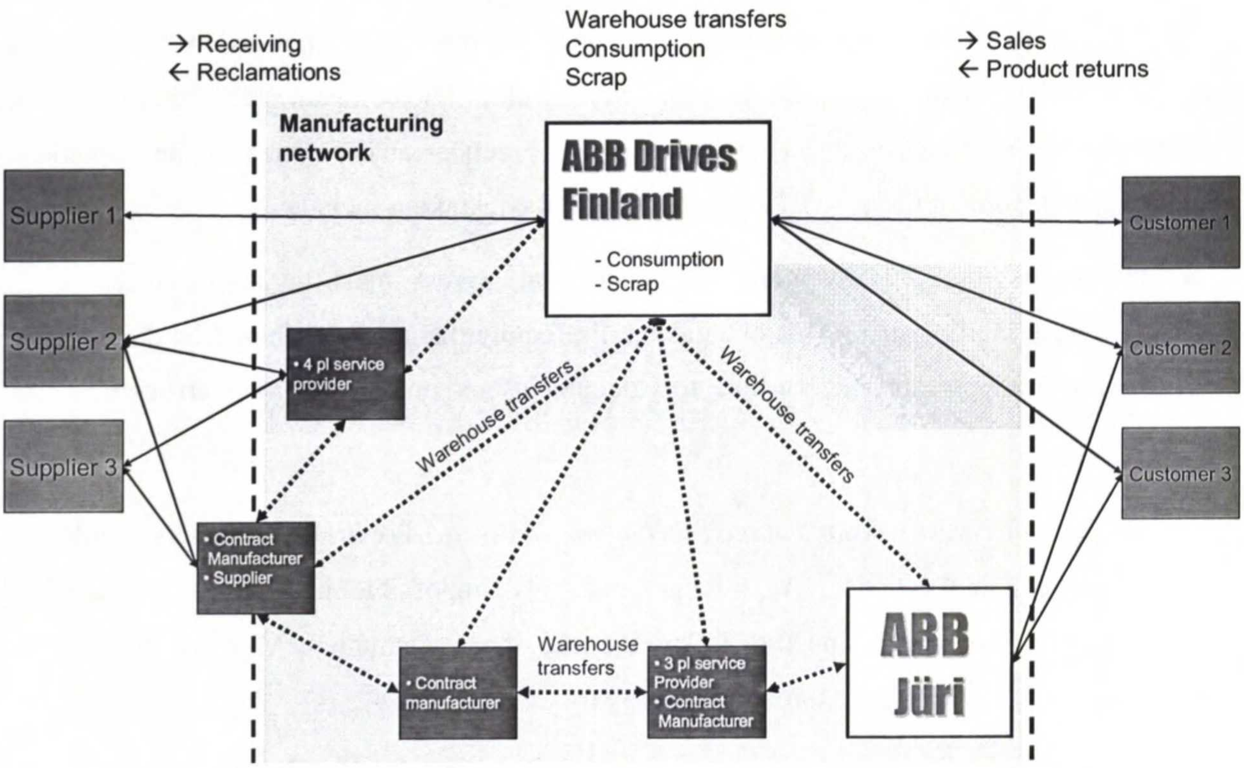
- Documentation: All inventory documents and -errors must be approved by a supervisor and paper records maintained. Preferably the approval should be done by two separate persons: one for inventory documents and one for inventory errors.
- Measures:
    - *Rate of current assets counted throughout the year.* Preferably all assets should be counted at once. As this is practically impossible in Drives' situation, accounting auditors need to follow the rate of assets counted. All items must be counted at least once throughout the year.
    - *Inventory turn.* Inventory turn is calculated with the following formula:

$$\boxed{\text{Inventory turn} = \frac{\text{The cost of goods sold in a year}}{\text{Yearly sales}}}$$

Formula 6 Inventory turn.

Inventory turn is one of the basic financial figures reported by companies. Cycle counting documents provide the necessary data for calculating the cost of goods sold used in the formula.

ABB Drives operates in the fields of power technology and industrial automation. It has assembly operations in China, Estonia, Finland, Germany, and the U.S. This case study covers only the Finnish head unit and operations in Estonia which are organized under ABB Drives Finland. Fast growth in the power technology market – which is due to the global energy-saving trend combined with the positive growth of the world economy – has caused Drives to re-think and diversify its supply chain. In order to respond to the demand, the company has outsourced fundamental logistic services, as well as some of its production capacity. Drives Finland, together with ABB Jüri and a selection of Finnish partner companies, form a production network, which is illustrated below (picture 4-1).



Picture 4-1 Map of the Supply Chain.

Parties involved in the manufacturing network (grey area of picture 4-1) are ABB Drives Finland, ABB Jüri (Estonia), and four partner companies with different roles. The functions of the partner companies (outsourcees) include:

- Warehouse space and –operations, transportation and replenishment services (3pl and 4pl service providers)
- Contract manufacturing

Picture 4-1 also lists the general types of transactions. Inventory record errors occur when transactions do not match real-world material movement. Therefore one of the first things to do when assessing accuracy problems is to map the types of transactions used. Transactions that take place at the borders of the network (receiving, reclamations, sales and product returns) are those where ownership over material is changed. Errors in these affect payments between ABB and its suppliers or customers. Therefore these transactions are closely monitored and errors are usually corrected shortly after they occur. Thus these transactions do not cause much inventory discrepancies. Most of the inventory errors are caused by material movement and consumption within the network and its facilities. Warehouse transfers for example do not change the ownership of the material in question, but errors in these manifest themselves as wrong stock location and errors at separate facilities balance each other; when one facility has too much stock of an item, some other is missing the same amount. There is no direct financial effect if the shipment is not actually lost, but the operational effects might be very harmful, because material can not be used where it should be.

Transactions that occur within the production network can be divided into two major subgroups:

- Internal transactions - Internal material consumption by departments and production phases inside a facility. A vast number of these transactions are performed all the time. There is significant chance for error, but the monetary significance of an individual transaction tends to be small.
- Warehouse transfers - Truck loads or smaller quantities transported between supply chain members. The number of transactions is smaller but errors cause large swings in the inventory accuracy of an individual facility until it is noticed and corrected.

A large part of internal transactions have been automated at the case company. This removes data entry work and saves time, but brings other problems. The automation of material usage in the ERP system is called *routing*. A significant amount of inventory errors involves routings, which take place based on production phase-specific material requirement lists in the ERP system. Routings cause errors in two ways. One is when the material requirement list has a mistake (e.g. wrong component or quantity). This is a significant source of stock discrepancy because the error is repeated each time when the product (or semifinished product) is assembled. The second type of error related to automatic routing happens in dynamic counting, i.e. when stock is counted while production is running. The error is caused when routing deducts the inventory balance of a stock keeping unit before or after the actual picking from the shelf takes place. This error is always temporary as it is neutralized when both events have occurred. The error can be either positive or negative depending on the sequence of picking and routing. If both actions would take place simultaneously, this error would not appear. Picture 4-2 is an example of how the error emerges and disappears. The example is a case with a MRP (material requirement planning) requirement of 2 pieces of a given SKU, and an initial inventory balance of 10 pieces:

Picking first leads to a temporary negative error:

Action sequence	Initial value	Picking	Routing
Shelf stock	10	8	8
ERP balance	10	10	8
Error	0	-2	0
Time			

Routing first leads to a temporary positive error:

Action sequence	Initial value	Routing	Picking
Shelf stock	10	10	8
ERP balance	10	8	8
Error	0	+2	0
Time			

Picture 4-2 Temporary routing errors.

As there are several units of semifinished products in different production phases at any given time, there is always a lag between ERP- on-hand quantities and actual shelf availability; although for an individual transaction the error is temporary. Duration of the time lag depends on lead-time and routing settings and varies from one production phase or product to another. The problem can naturally be avoided by counting outside active production hours and finishing all pendant picking tasks before beginning to count, but this substantially limits the time available for counts and brings other problems as well. The advantages and drawbacks of these off-hour counts are discussed in chapter 4.3.1.

4.1. Analysis of ERP System Accuracy

The first step in defining the needs for accuracy improvement consists of measuring the aspects of inaccuracy. The following table is a summary of related metrics (table 4-1).

	ERP accuracy statistics	2005	2006	2007
1	Total n. of SKUs counted	11 963	11 082	13 172
2	Growth	-	-7,4 %	18,9 %
3	SKUs counted (no duplicates)	10 570	10 131	12 050
4	SKUs with zero stock level	3 768	2 680	3 978
5	Erroneous SKUs (all counts)	4 937	4 631	4 980
6	Erroneous SKUs (tolerance +/- 2 %, no duplicates)	3 810	3 697	3 834
7	Accuracy level (good count/bad count)	64,0 %	63,5 %	68,2 %
8	On-hand weighted error	15,68 %	15,26 %	11,75 %
9	Total accounting difference	-266 659,82	-5 365,16	-240 369,73
	Error distribution (population = erroneous SKUs)			
10	Average error	-54,01	-1,16	-48,27
11	Median error	-9,52	-11,68	-13,85
12	Mode error	-0,11	-0,11	-0,22
13	Standard deviation of errors	4 074,01	2 132,02	1 457,02
14	Error range	236 106,19	139 720,79	72 916,98

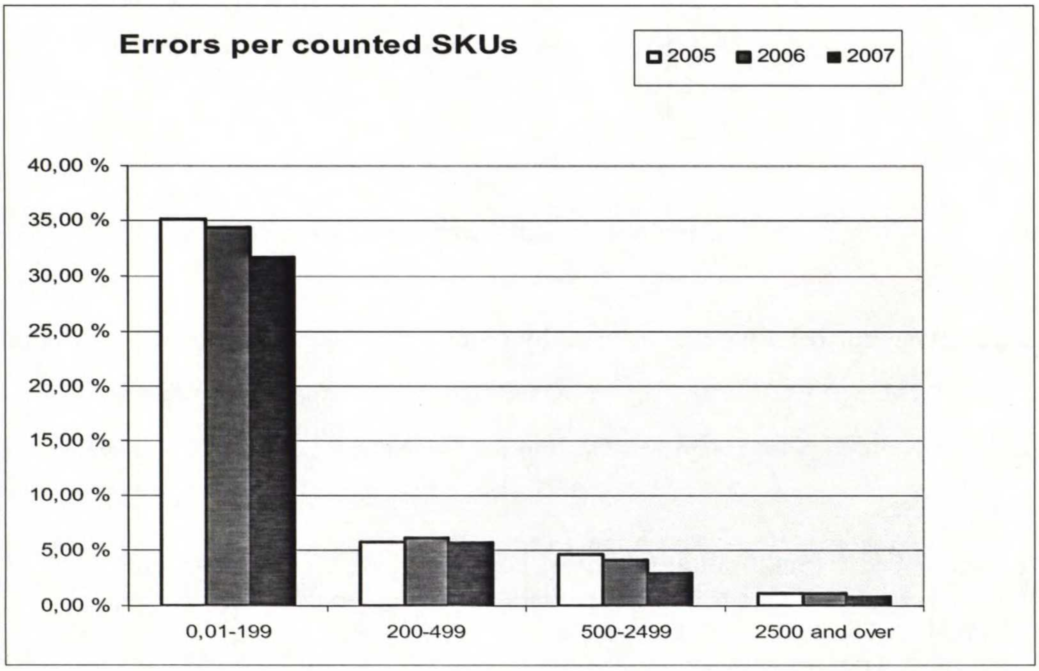
Table 4-1 Summary of Accuracy Statistics at ABB Drives.

As table 4-1 shows, there is a remarkable number of items that must be counted each year. On top of that, managers expect the number of SKUs to continue growing in the future. The fact that a large part of the SKUs has a zero stock level (compare rows 3 and 4) indicates that a large part of SKUs are not used at all. This means that each year cycle counting work time is wasted counting these "zero lines", as accounting legislation says all items must be counted regardless of the system showing no stock.

The overall accuracy level (row 7), which is obtained from the number of SKUs with accurate records divided by the total number of SKUs counted, is below the medium level across industries (68,2 % in 2007 compared to Piasecki's benchmark figure of 50-100 %, with a medium of 75 %, Piasecki 2003, 174-177). This measure seems to be the most commonly used in accuracy programs, and is sometimes called *the good count / bad count measure* (Piasecki 2003, 152). Compared to Piasecki's recommendation for manufacturing companies – which is between 88 % and 98 % – the accuracy level seems almost alarming (Piasecki 2003, 174-177). Also the considerably large total accounting difference (row 9), which reduces current assets in the balance sheet, signals that inventory accuracy is not at a satisfying level. For instance, in 2007 ABB Drives directly suffered an accounting difference expense of more than 240 000 €, not to mention the indirect accuracy costs that have not been measured. Total inaccuracy expenses would be much more than 240 000 €, possibly even hundreds of thousand euros more, as explained in chapter 3.2.2.

What comes to the distribution of errors, the average-, median- and mode error values indicate that most of the errors are quite small, while a few very large ones increase standard deviation and widen the range. Typically the errors are negative, but not by much. Most of the negative errors are countered by positive errors, leading to less inventory difference than would otherwise be the result.

Regarding the development of inventory accuracy over the last three years the first two years were almost identical, but in 2007 some positive changes took place: The accuracy level (row 7) increased from 63,5 % to 68,2 %, while the weighted on-hand error (row 8) decreased from 15,3 % in 2006 to 11,8 % in 2007. A somewhat meaningful improvement has been the removal of some of the biggest errors, resulting in a smaller range and standard deviation, and a slightly smaller error average. Distribution of inventory errors by error size is shown in detail in appendix 2. In any case, it is a positive remark that compared to the growth in the number of SKUs, the company has done well in controlling the situation. Although sales, the number of SKUs, and stock levels (appendix 3) have grown substantially in the recent years and the number of inventory errors, as well as total accounting inventory difference (table 4-1) have increased, relative inventory accuracy has improved. It means that the number of erroneous SKUs has not increased as much as would be expected compared to growth. Picture 4-3 illustrates the proportion of errors – absolute error by SKU – by size classes over time.



Picture 4-3 Errors per counted SKUs.

To gain a better understanding of the error distribution it is useful to rank the items based on absolute inventory record error. The approach is similar to the basic ABC analysis, but instead of ranking the items based on financial usage, they are sorted by error size. Table 4-2 demonstrates what proportion of stock items is sufficient to cause each of the signpost figures (50, 75, 90 and 99 percent) of the cumulative absolute error. The related pareto curve can be found in appendix 4. The results are evident: a small minority of the stock causes most of the errors. Just one percent of items cause half of the total absolute difference, while less than 30 percent cover 99 % of it. The analysis suggests that finding the right ABC classification criteria or otherwise defining the problem SKUs would greatly help when focusing improvement efforts.

	Percent of SKUs			
Cumulative error	**2005**	**2006**	**2007**	**Average**
50 %	1 %	1 %	1 %	**1%**
75 %	3 %	5 %	5 %	**4%**
90 %	9 %	12 %	12 %	**11%**
99 %	26 %	28 %	27 %	**27%**

Table 4-2 Cumulative absolute error by stock percentage.

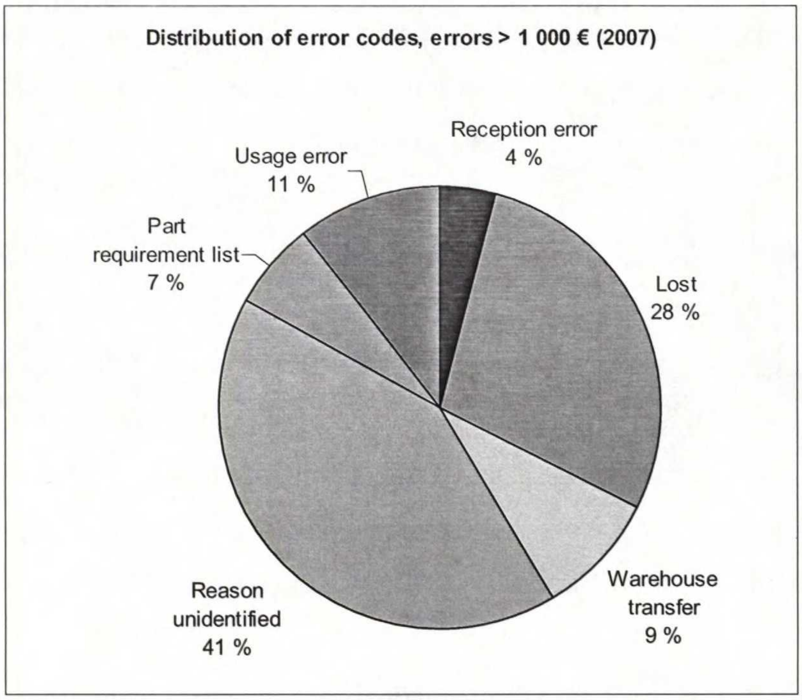
To take the analysis further, stock is grouped by component type. Next the groups are ranked by the same factor that was used in the previous analysis, that is the absolute inventory difference. Table 4-3 lists the ten component groups causing the largest errors

Top ten component groups	Error %	Error % (cum.)
1. Circuit boards	29 %	29 %
2. Transducers	6 %	35 %
3. Profibus	5 %	39 %
4. Bus bars	4 %	43 %
5. Capacitors	3 %	46 %
6. Fans	2 %	48 %
7. Heat sinks	2 %	51 %
8. Diodes	2 %	53 %
9. Chokes	2 %	55 %
10. Packing boxes	1 %	56 %

Table 4-3 Top ten erroneous component groups.

Performing the analysis shows that the 10 largest item groups cause 56 % of total inventory difference, while the 50 largest groups account for 64 %. The largest group, circuit boards, causes more inventory error than all the other top ten groups together (29 % versus 27 %). The reason for this is that circuit boards are costly, with an average unit price of 50 € and they are used in large quantities in assembly operations. As a conclusion to the analysis, it can be said that circuit boards, and maybe also transducers and profibus should be treated with special attention. The same analysis could be easily performed in a departmental level to identify the biggest problem causers.

Error cause reporting is an ERP tool that has been used at ABB Drives only since 2006. The reason for its introduction was the Sarbanes-Oxley act, which requires a formal system for solving inventory discrepancies and a record of past error causes. The system is still in transition, as not nearly all of the error causes are entered. Of all errors, only 15 % were given a cause in 2007 (appendix 5). It is though not feasible to investigate all errors, but even with a tolerance of +/- 200 €, only 40 % were reported. If we then look only to errors exceeding +/- 1 000 €, the reporting rate increases to ~ 60 percent. There are 6 different error type codes in use. The following pie chart (picture 4-4) demonstrates the distribution of reported error causes, when looking at errors +/- 1 000 € that took place in 2007. Appendix 6 shows the overall distribution in 2006 and 2007 in a more detailed manner.



Picture 4-4 Distribution of error codes.

The outcome is that in a good 40 percent of the cases the reason could not be identified. If we add this 40 % to the initial figure of 40 % of errors that were not reported in the first place, we get an identification rate of only 36 percent (60 % out of 60 %) for all errors exceeding 1 000 €, which seems pretty low. It is important to notice however, that the errors entered in the ERP system are only a part of all errors detected. When an employee detects an error during a count, he/she tries to find the cause and correct it right away so that it would not have to be entered. Therefore a large part of the apparent errors is not shown in the statistics. This problem will be discussed in chapter 4.4.3 along with the introduction of an improved cycle counting and reporting process.

4.2. The Cycle Counting Process – Status Quo

This is a description of the currently used cycle counting process at ABB Drives. The aim is to get a comprehensive understanding of current stocktaking practices.

This process description is based on observations made during an actual cycle counting training period of three weeks, which was the first qualitative evaluation of the case company. The training took place at the largest of the three profit centers operating inside the Drives Helsinki factory. Apart from the observation period, the process description is based on professional counters' insights and Drives' official work instructions.

Individual employees' cycle counting methods vary in some aspects. There are also distinctions in some accrual policies between profit centers. For example missing shipments can be treated as inventory differences in one profit centre and directly removed from inventory balances in another. Nevertheless the chosen profit center is the best representative of the whole factory, because when it comes to supply chain management and product requirements, its operations are the most complex and geographically wide-spread. Therefore a solution developed for this profit center should be applicable to the others as well.

There are two main procedures for performing counts:

- Cycle counting
- Counting outside cycles (same as continuous physical inventory)

The essential difference between the two processes is the scheduling of the counts of different stock keeping units (SKU's or items). Cycle counts are scheduled using pre-specified ABC - classifications in the ERP-system. Currently all SKU's are counted only once a year and outside the scheduled cycles, so basically only the second procedure is being used.

The second way to perform counts is to specify the schedules using personal judgment and whatever data and information affecting the counting task. Usually counters use a report of SKU's not yet counted during the ongoing year, as well as storage value data and prior knowledge of individual counting characteristics of different groups of SKU's or different kinds of production lines.

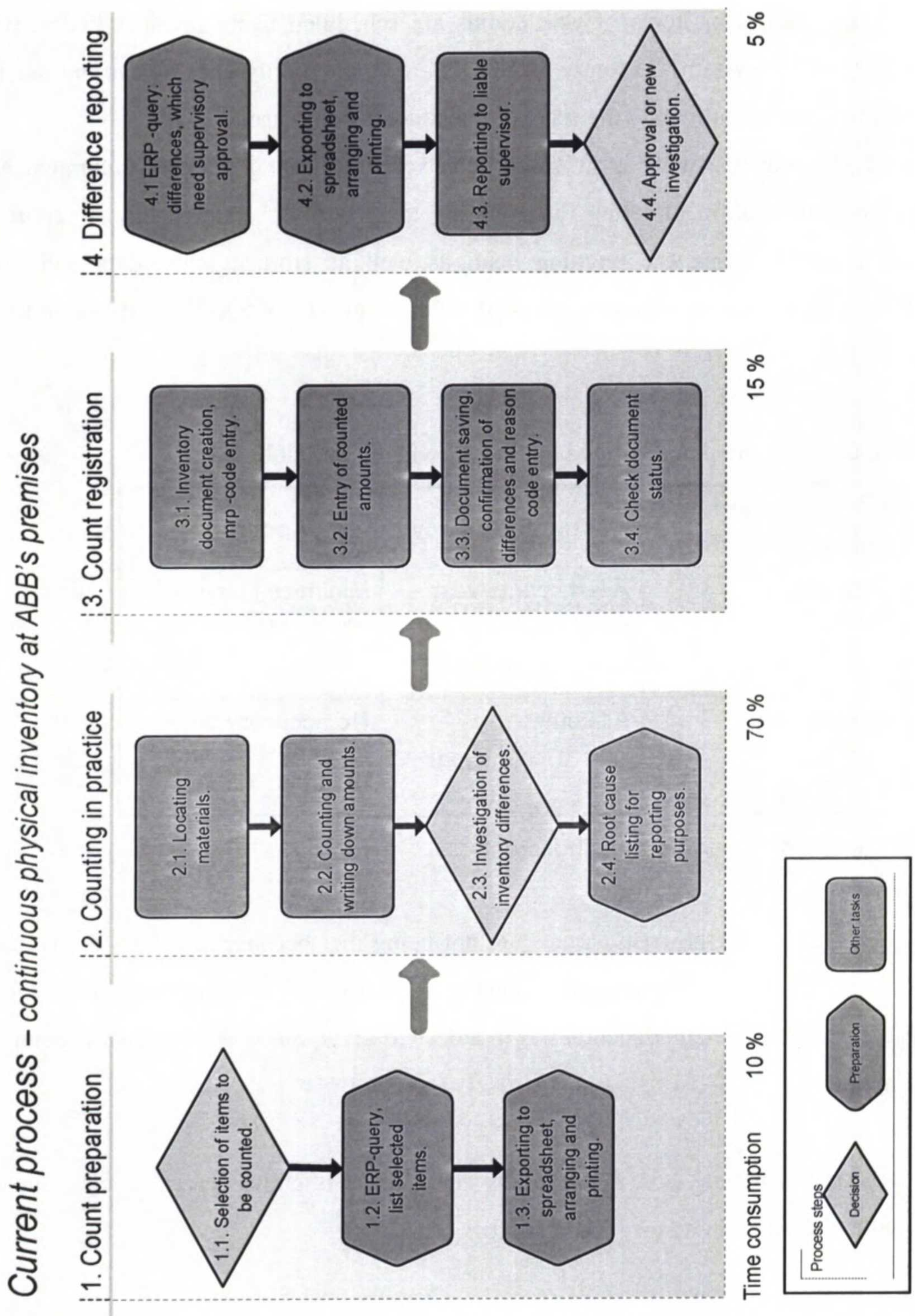
Targets for cycle counting are demonstrated in the following table (table 4-4):

Target / Function	Count frequency	Accuracy
Logistics / Production	A – 4 counts/year B – 2 counts/year C – 1 counts/year	Minimize inventory record errors.
Accounting	All items 1 count/year	No accuracy targets (except stock loss reporting accuracy).

Table 4-4 Cycle counting targets.

As was said above, currently the ABC-targets are not being met because all SKUs are counted only once in a year. What comes to accuracy, there is no defined level of accuracy. Therefore it can not be objectively said, whether accuracy is in a desired level. Summing up, only accounting targets are being met.

The following picture (picture 4-5) is a process chart describing the current cycle counting process (continuous physical inventory) used at ABB.



Picture 4-5 Current Cycle Counting Process.

The process is divided in four phases (*Count preparation, Counting in practice, Count registration* and *Difference reporting*), which include 3 to 4 steps each. The counting process is described step-by-step in chapters 4.2.1 to 4.2.5.

4.2.1. Count Preparation – Decision Basis for Selecting Items

The basic rule for selecting items is to select an easily definable group that has high financial value and is easy to count. Preferably the items should be located near to each other. Usually a stocktaking rate report is used to see which items would best raise the overall percentage of current assets counted during the year. The report shows how much has been counted from each product family. The mere report is not enough though, but the counter must consider specific characteristics of each SKU and production line the SKU is used in, e.g. some items may not be counted while the corresponding production line is operating.

The group of items to be counted usually consists of SKUs belonging to one specific product family. Sometimes inventory is also counted one aisle at a time, involving intersecting responsibility areas of two or more cycle counting clerks.

Purchasers or production line personnel also often request specific items to be counted, usually relying on the know how of cycle counting clerks in correcting erroneous transactions. These requests bypass the normal counting sequence, because they relate to urgent operational issues, such as purchase orders and material transportation.

One standard way of selecting SKUs for counts does not exist at ABB, but the work experience and knowledge of the cycle counting staff play a major role. However, here is a summary of requirements an item must fulfill in order to be counted:

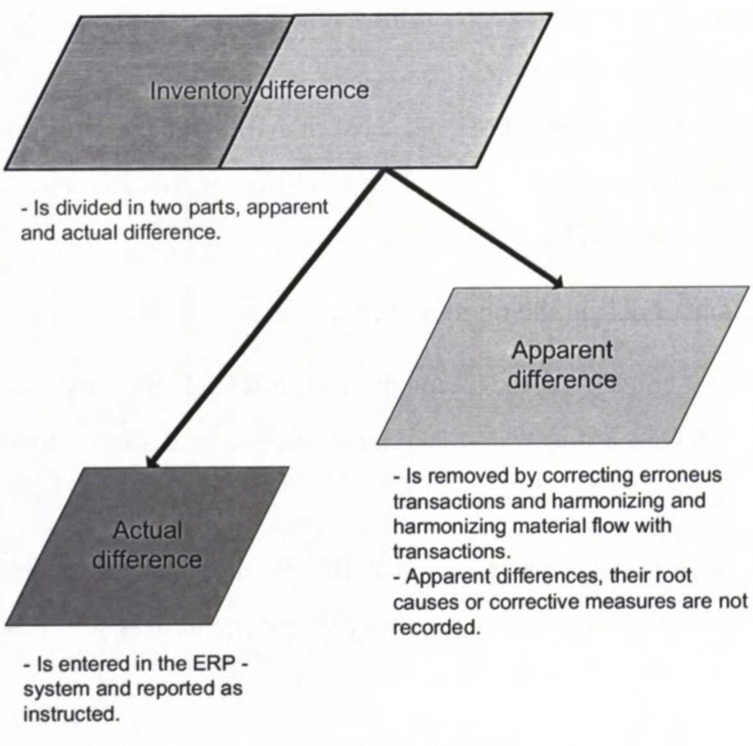
- The item has not been counted during the ongoing year.
- The production line that consumes the item is not affected by any special arrangements – such as layout reforms – that cause excessive disorder to daily transactions.
- The item is physically accessible. This means that the counter has the necessary material handling equipment available and the hallway where the item is stored is not blocked anyhow.

4.2.2. Cycle Counting in Practice – Locating Items Physically

Normally each item is given designated primary and secondary storage bins as well as work posts where the item is used. These data are maintained in the ERP –system. There is also a picture database that the counter may use for identifying components. Basically, the locating of items is done by simply following these location information, but misplaced inventory and neglected updates make it often very hard in practice. In this kind of situations the counter has to rely on the help of other factory personnel. As was the case in the previous chapter, there are multiple ways of locating misplaced inventory. This task is also situation-specific.

4.2.3. Cycle Counting in Practice – Investigation

When items are counted for the first time, differences are remarkably large before they are investigated. As reasons are found, erroneous transactions are corrected and the total difference of counted SKUs decreases substantially. The remaining part makes the actual inventory difference. The idea of investigating is to remove all apparent mistakes so that the remaining inventory error would be as small as possible. Picture 4-6 illustrates the breakdown to apparent and actual differences:



Picture 4-6 Actual and apparent difference.

Investigation is the most demanding task related to the cycle counting process and it is also one more task that requires experience and comprehensive understanding of prevailing material flow processes. Investigation includes interpretation of transaction history in the ERP-system, consulting other employees within the plant and at external warehouses and correction of previous faulty transactions. ERP –systems vary from one company to another, but the following is a generic list of transaction types to be investigated:

- Transaction history by item.
- Material consumption for standard production.
- Material consumption for customized production.
- Material transfers between facilities.
- Material transfers between profit centers.
- Material requirement for sales orders.
- Material transfer from a sales order to another.
- Material used for warranty compensation.
- Previous inventory counts and balance corrections.
- Purchase order quantity and invoicing.
- Scrap and reclamations (to suppliers).
- Spare part sales.
- Transfers from warehouse to research and development.

ERP –queries used at ABB. The following is a list of reports designed for tracing material consumption by production phases and products.

- Inventory record, current warehouse transfers and blocked SKUs.
- Material requirements list of products – check for discrepancies.

- Routings – shows material usage in products.
- Supplier information of SKU.
- Reclamations for refund bill and reclamations for replacing delivery.
- Cog -list: A list of errors caused by picking material with zero or blocked inventory.
- Profit centers where the SKU is used.
- Comparison of reception documents and invoices.

4.2.4. Cycle Counting in Practice – Root Cause Listing and Difference Reporting

Root cause listing means the recording of the reasons for inventory differences that are to be reported later. There is a policy that dictates entering root causes for inventory differences in the ERP system. Apart from this standard record employees maintain their own records in paper files and spreadsheets, because the standard ERP record is not informative enough.

ABB has a policy that dictates that all inventory differences exceeding a certain financial value must be reported to the liable purchaser or production manager for approval. In practice though, the liable person does not have much choice but to sign the inventory difference list as proposed by the counter, because SOX requires a report every three months. The accounting function follows these reports closely, but they are not used for the purpose they should in theory, that is improving operations.

Apart from these official reports, the counters also give unofficial feedback to the production managers, so they could fix the more significant material accounting errors. However, despite the fact that these errors cause waste of time and resources, a major problem in the current situation is – as seen by every cycle counting clerk involved in this study – the production managers' indifference to inventory accuracy goals. Also in general people working at different positions and departments at the case company have conflicting views of inventory accuracy issues and their importance.

4.3. Performing Cycle Counts at External Warehouses

As demonstrated in the picture 4-1, ABB Drives has a complex supply network, and Drives' current assets are spread among diverse kinds of locations within this network. When it comes to inventory accounting, ABB assumes full responsibility of these stocks. Because of its responsibility and the lack of stocktaking expertise at partner companies, cycle counting is mainly performed by ABB personnel. Each partner company has its unique operating circumstances, and therefore counting conditions at each network location diverge. The purpose of this chapter is to describe the generic counting process, which is a synthesis of cycle counting approaches for individual locations, applied at external warehouses.

4.3.1. General issues

Among other things, cycle counting work and resource needs depend on the following characteristics:

- Plant type: Whether it is a warehouse or a factory (or a combination of the two) determines how small quantities the SKUs are kept in and how complex its operations are.
- Production process characteristics: Lead-times and the number of manufacturing phases determine the complexity of work in progress –inventories. Complex and / or fast moving production lines must be stopped when they are counted.
- Number of SKUs: Determines the number of rows to be counted.
- Warehouse size: The larger the plant (physically and financially), the more time and people are needed for counting it and the more its stock affects the company's balance sheet, making it important to control.
- Congruence of information systems (ERP discrepancies): Whenever divergent it-systems are used, there is a need for local computer assistants and cycle counting work is slower.
- Company ownership (partner vs. ABB subsidiary): Affects power relations, which determine how easy it is to arrange resources and introduce new practices.

- Travel time from ABB Drives Helsinki: Determines how many visits can be made to perform the counts.

At the beginning of the year cycle counters at Drives prepare a counting plan for each external warehouse. Taking the above characteristics into consideration, the plan includes at least a timetable, a list of relevant plant-specific problems and necessary preparations including the designation of resources and responsible workers. Some facilities are counted in a few working days, while others are counted little by little throughout the fiscal year.

The cooperation and trust between Drives' counting personnel and contact persons at external warehouses is crucial. From ABB's point of view there are sometimes reliability problems in the inventory data provided by partner companies. Mostly this is a question of missing ERP expertise and insufficient count verifications, and it could be solved with proper training and adequate labor resources.

Depending on the product and its production process, counts may be executed when production is running or when it is stopped, i.e. during evenings or weekends. In other words, when counts can be performed is a question of whether production must be frozen or not. If stopping is necessary, inventory may only be counted outside regular working hours. Otherwise it can be done whenever wanted. Production is never stopped for a physical inventory during weekdays, because it would be too expensive as for its benefits. Weekend counts may often make cycle counting work easier, but also have some drawbacks. Weekend- / evening count's pros and cons include:

+ Production is at its minimum, so the ERP –situation reflects reality more precisely.

+ Less ongoing transactions, easier ERP –investigation.

+ Counting personnel are not disturbed by simultaneous tasks or other interruptions; distractions are at their minimum.

→ Off-hour counting work is faster and more effective.

- Overtime work (work costs more and diminishes productivity, harder to get workforce). Though weekend and evening work might be compensated with free time in regular working hours, thus not costing extra. This however requires good work sequencing.

- Production and purchasing personnel are absent, so they can't be consulted.

4.3.2. Practical Arrangements

Performing cycle counts at external warehouses requires being physically present at the location. As the distance between facilities is several hundreds of kilometers in some cases, counting trips must be carefully planned in advance. This chapter outlines the practical issues involved with counting external warehouses as it is currently organized at ABB Drives. These issues must be taken into consideration when planning counts.

First of all, there are two basic types of planning meetings:

1. Well before the stocktaking visit a meeting is held for listing probable troubles known from previous years and which need to be addressed up front.
2. Closer to the visit date the stocktaking team gathers again and goes through the problems for defining which of them have been solved and which have to be solved on-site.

Forklift operators and cycle counting clerks need to be designated for the task. For this purpose, it is necessary to know how much work there is to be done in location. The amount of work is estimated by using the ERP –system data and contacting the external warehouse. At this phase, it is sometimes possible to fix some of the biggest inventory errors beforehand. The production process and related ERP –routings and part requirement lists are also issues to be solved in advance when planning to count semi-finished or finished products. Based on these clarifications, instructions are written for later use on-site.

Based on the estimated work-load, planners try to reserve sufficient resources. Resources needed for performing counts include:

- Time
- Number of expert cycle counting clerks from Drives

- Number of local assistants, including factory guides, assistant cycle counters, forklift operators and IT help.

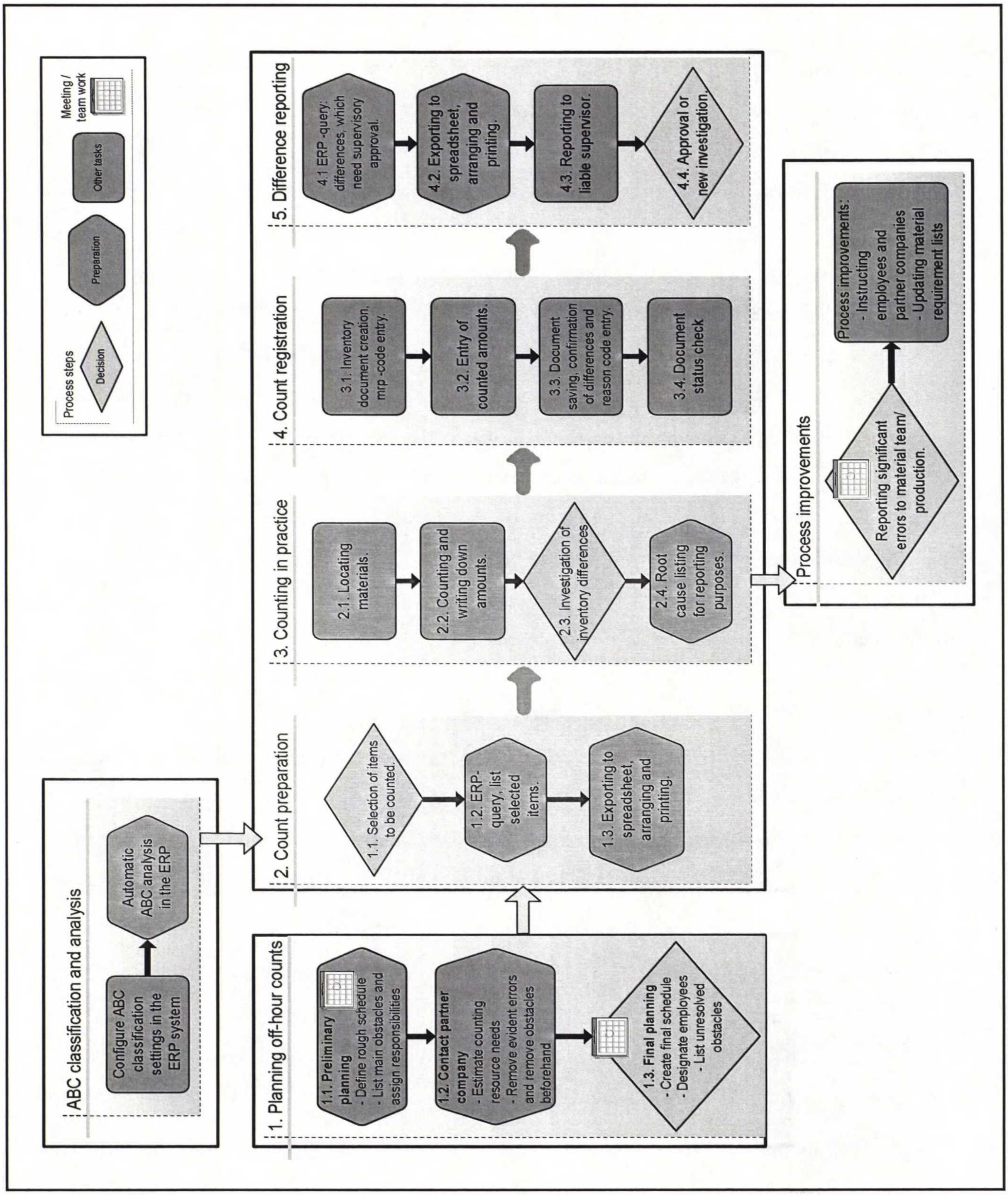
Cycle counting work has to be done on-site, error investigation and recording may be done later at Drives Helsinki. Investigation and recording can also be done on site, if the cycle counting clerk has access to the ERP –system. However, demanding investigation cases mostly have to be solved at ABB's premises, as they take a lot of time.

Location information and pallet markings have to be accurate and up to date, so time is not wasted looking for missing material. For every cycle counting clerk there is a local assistant whose main role is to be a factory guide knowing where each material is stored, but who can also help with IT-issues. If ERP-entry and investigation is planned to be done on-site, a work post must be arranged for the person doing the task.

Currently most external warehouses require more than one visit each year. With all the planning and traveling involved, it takes a significant part of the cycle counters' time. Possibly in the future stocktaking responsibility will be shared so that external warehouses arrange counting tasks partly or entirely on their own.

4.4. The Improved Cycle Counting Process

The case study revealed three important areas of the cycle counting process that need established procedures. These are the planning of off-hour counts, the selection of ABC classification criteria, and a reporting procedure for material process improvements based on inventory error. Including these three added elements picture 4-7 represents the improved cycle counting process. The added elements are discussed in chapters 4.4.2 and 4.4.3, except for the planning procedure which was already explained in the previous chapter (chapter 4.3.2).



Picture 4-7 The improved cycle counting process.

4.4.1. Amount of Work in the New System

Appendix 7 contains calculations of how much more work would be required, if part of the stock would be counted more often. The assumption at this point is that only the number of counts is changed (allocation of items to ABC classes and the number of times each class is counted). Cycle counting work at external warehouses is addressed separately in chapter 4.4.4.

The calculations suggest that the amount of counting work would increase by 40-80 % in the short term. In labor hours this means an additional 1 to 3 man-years, depending how items would be assigned to ABC classes and how efficient the work would be. If all the extra work would be performed by new personnel, this would mean a labor cost increment of 40 000 to 130 000 euros. In reality work would become more effective, especially because errors could be investigated sooner than before and they would thus be easier to solve. Labor costs would not increase as much as calculations suggest, because part of the added work would be performed by old employees. Employment needs would need to be measured separately for each department.

Further analysis of increasing cycle counting work is performed in chapter 4.4.4.

4.4.2. Evaluating ABC Factors in Practice

In the theoretical part of this study several ABC factors were presented. With the exception of two initially unsuitable ABC factors – transaction activity and inspection cost – this chapter evaluates their fitness for use in the case company. Also the error-predicting value of some of the ABC factors is evaluated quantitatively. Based on the analysis, suitable factors are selected for use in the case company.

- **Usage value** (financial value of consumed stock). This is the most popular ABC factor in existing research, and it is also the only factor readily available in ABB Drives' ERP system. Usage value is a good predictor of inventory errors, as will be demonstrated later in this chapter.
- **Previous inventory errors** (some items cause errors from year to year). Part of the errors repeat themselves year after year. Therefore previous inventory errors contain some predicting value. This factor is not available for automatic ABC analysis in the

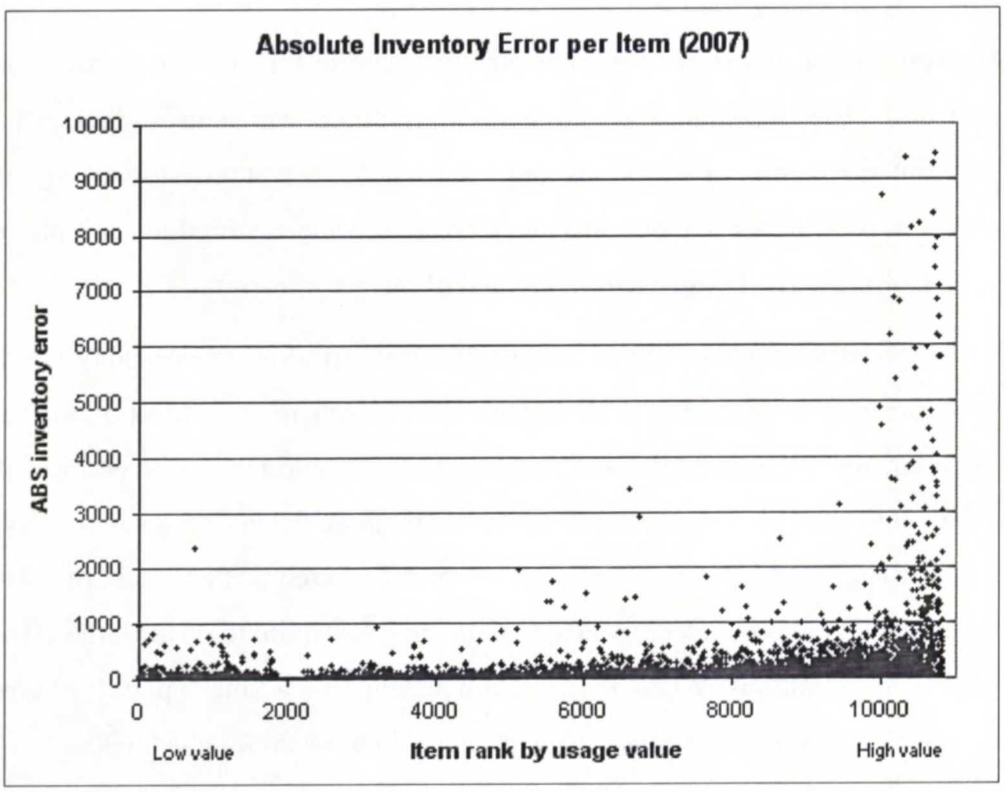
ERP system, but items with errors can be assigned to the A-class manually so that they can be monitored more closely. The predicting value of previous errors is investigated at the end of this chapter.

- **Item commonality** (components used in several separate products are prone to errors). There is no data available about how many assembly phases use a certain item. The evaluation of this ABC factor and gathering the required data would require extensive work compared to the possible gains. Therefore item commonality is left outside the scope of this study.
- **Material stored at external warehouses** (warehouse transfers are a major source for errors). The appearance of an item in multiple warehouses does not have significant predicting value for inventory errors. In fact, items stored only at one location have a higher average inventory error than those stored at multiple places (appendix 8). Therefore this factor is left out of further evaluation.
- **Product criticality** (risk policy –based classification). Product criticality is a factor that is currently monitored at ABB Drives. However there is no function in the ERP system for using it as an ABC analysis factor. This could though be performed as a manual function: whenever a supplier has difficulties delivering an item, this item could be manually locked to the class A. It shold be noted that product criticality has no predicting value on inventory errors. Criticality has more to do with the effects an error has on operations: When a critical component with a long supply lead time has a negative error, this could cause large problems to production schedules.

As discussed already in the theoretical section of this study, usage value is the most common factor used for ranking the inventory. The following analysis explains why it also works in practice.

To evaluate the efficacy of usage value as a predictor of inventory errors, a set of data was gathered. This data included financial inventory errors per stock keeping unit in the years 2005 to 2007, as well as average purchasing prices in euros and material usage volumes for each item.

Usage volume was multiplied with price to calculate the usage value of each item. After that the data was arranged in a way that each line consisted of the material code, usage value, and inventory error of an item in a given year. Sorting this data based on usage value and using absolute values of inventory errors instead of net values (+ and -) gives some understanding of how inventory errors are distributed. Picture 4-8 illustrates inventory error data from year 2007 plotted in a chart.



Picture 4-8 Inventory errors ranked by usage value (2007).

Picture 4-8 shows clearly how the larger errors are packed to the right side of the chart. This suggests that on average the items with a higher usage value are the ones with more inventory errors. To take the analysis further, linear correlation was calculated between the rank numbers of SKUs and the cumulative proportion of inventory errors (appendix 9). It turned out that there was an average linear correlation of 0.80 between these two factors when looking at the data from years 2005-2007 (table 4-5). As correlation was evident, the data was analyzed with a variation of the classic ABC analysis method. In the classic method data is plotted to see which proportion of line items form each proportion (e.g. 50, 75, 90 and 99 percent) of the cumulative usage value. In this variation cumulative financial error was used instead of usage value. Usage value was also used, but only in the ranking phase. The results can be seen in table 4-5. On average it takes just 3 % of all items to cause 50 % of the cumulative absolute inventory error, while 75 % is caused by 13 %.

Based on the results, items were set to classes using integers of 5 percentage units for practical reasons. Class A consists of the first 5 % of items, class B includes the next 10 % and the rest of the inventory was assigned to class C, which thus includes 85 % of all stock keeping units. None of these changes were made in the real ERP environment, but only in separate spreadsheet calculations (appendix 9). By systematically setting the ABC indicators to items, it was possible to see how much of the cumulative inventory error would have fallen into each category if such classification would have actually been used in the previous years. The results can be seen in table 4-5. It turned out that ~60 % of the cumulative error would have been covered in class A, while the remaining ~40 % would have fallen quite evenly between classes B and C.

	2005	2006	2007	Average
Linear correlation	0,83	0,76	0,80	0,80

	Limit reached at (% of SKUs)			
Cumulative error limit	**2005**	**2006**	**2007**	**Average**
50 %	3 %	3 %	4 %	3 %
75 %	14 %	11 %	13 %	13 %
90 %	38 %	35 %	40 %	37 %
99 %	91 %	96 %	91 %	93 %

Applied class proportions	
A	5 %
B	10 %
C	85 %

	Error proportion by class					
	2005	**2006**	**2007**	**Average**		**Deviation**
A	60 %	63 %	54 %	59 %	+/-	4 %
B	16 %	17 %	23 %	19 %	+/-	3 %
C	24 %	20 %	23 %	22 %	+/-	2 %

Table 4-5 ABC classification based on usage value.

In summary, usage value has great advantages for use. Counting 5 % of items four times a year and 10 % two times would enable the company to get to grips with ~80 % of the total absolute inventory error. What this would mean to arranging the cycle counting work in the whole supply network, is discussed further in chapter 4.4.4.

An interesting notion of the past inventory error data was made already at an early phase of this study; it seemed that a significant part of the top 10 % of erroneous items had had problems already in the previous years. This implicates that even when large errors have been found, the necessary material process improvements have not been made. This finding is studied further in the following section.

In order to determine whether inventory errors repeat themselves year after year, Spearman's rank correlation coefficient was calculated (appendix 10). This method was selected because in ABC analysis the thing that matters is ranking rather than individual values. Compared years include 2005 & 2006, 2005 & 2007, as well as 2006 & 2007. As items needed to be ranked based on inventory errors, items without deviance in both years were left outside the analysis. Also duplicate items (items with several counts during a year) were removed so that each item would appear only once. Results can be found in table 4-6.

Years	**05 & 06**	**05 & 07**	**06 & 07**
ρ	62,5 %	54,5 %	67,4 %
n	1862	1595	1907
n %	40,9 %	38,3 %	45,8 %

Table 4-6 Error permanence at Drives.

Calculation parameters include the following:

Years = Years whose inventory errors are compared

ρ = Spearman's rank correlation coefficient

n = Amount of line items that had an inventory error in both years n % = n divided by the number of items with an inventory error in the latter year. Total number of erroneous items (no duplicates) was 4550 in 2006 and 4166 in 2007.

Summing up the use of past inventory data as an ABC factor it can be said that during the last three years about 40 percent of the erroneous items remained the same. Regarding the absolute error magnitude of these items, correlation clearly exists. Between two consecutive years the correlation coefficient is over 60 percent, which means that a large part of the more significant errors occur repeatedly to the same few items. The result suggests that items with higher variances in the previous year should be monitored more closely (perhaps assigning them the A class indicator manually). It should be remembered though that merely counting and correcting errors is not reasonable in the long run, if the same problems rise year after year. At least steady-state products, the production processes of which do not have to be altered constantly, should have efficient and well-defined procedures in place. What would help to improve operations, is binding production and logistics managers to correct the mistakes that cycle counters come across with. This would require a new policy, where cycle counting clerks, whenever detecting a significant and repetitive mistake, would have the means of informing the responsible logistics/production employees so that the error would be avoided in the future. In other words, when the counter would see it necessary, he or she could give an official notice to the manager. This notice would then have to be justified with evidence gathered in the investigation process.

4.4.3. General Cycle Counting Strategy

The first and most important decision is to set accuracy targets. It is hard to determine what the accuracy level of a given company should be, but the metrics introduced in table 4-1 clearly seem low. The financial inventory error comes down to several hundred thousand euros, while the records of over 30 % of items are erroneous by more than 2 %. In an average basis the stock records deviate by more than 10 % of what they should be. The easiest way to set targets is to select a couple of these metrics and follow them on a yearly basis, trying to improve them compared to previous performance. They might even be used as a basis for employee compensation, but this is a subject that is left outside the scope of this study.

The ABC analysis criteria should be redesigned. Based on the analysis performed in the previous chapter, usage value should be used as the sole factor for automatic analysis using the existing ERP feature. Class proportions would be 5/10/85 for A/B/C and count times 4/2/1 respectively. This method may be complemented manually for individual items, e.g. when significant errors occur repeatedly or when a supplier has problems providing a certain item. Manual work in this case means basically locking a material code to a given class (usually class A), so that it will not change during the automatic analysis.

Off-hour counting should be implemented whenever possible, but without disturbing production unnecessarily during active production hours. The key here is to plan the counts well in advance. One way to facilitate planning would be to include production managers in the planning meetings. In this way there would be less surprises and sudden changes to the plans.

If managers at Drives want to make cycle counting work and error investigation easier for people who do not have comprehensive understanding of the material processes, errors should be reported more extensively. Picture 4-6 illustrated the division of errors into apparent and actual differences, from which only the latter ones are currently reported. The rest remains tacit knowledge of individual employees, but does not help the organization. The recording of these errors and their causes would easen the orientation of new employees, as they would get access to the information about past sources of error for individual items. It is important to note that apparent errors should not be recorded in the ERP system as usual, because this would cause unnecessary swings to stock levels. The maintaining of a spreadsheet file or an ERP database that would not affect stock levels would be a better solution.

In this chapter a general inventory accuracy has been suggested for the case company. Table 4-7 sums up the recommendations.

Cycle Counting Decisions		**Recommendations for ABB Drives**
General Decisions	Measure accuracy and set targets.	Financial inventory error < 200 000 € Accuracy level > 75 % (tolerance 2 %) On-hand weighted error < 10 %
	Define cycle intervals.	Counts per year: A x 4 / B x 2 / C x 1
	Select ABC factors and set items to classes.	Automatic classification: Usage value. Set problem items manually to class A. Proportions: A 5 %, B 10 %, C 85 %.
	Select between dynamic / off-hour counting method for individual production lines.	Some lines can be counted dynamically, while some only during off-hours. Off-hour method should be used more. Planning counts is essential.
	Define error investigation and reporting methods.	Enter only actual errors in the ERP system. Apparent errors should be recorded in a separate database (not defined). Report significant and repetitive errors to the material team and other errors according to SOX requirements.
External Warehouse Decisions	Select between dynamic / off-hour counting method for each facility.	Off-hour counts should be the default method. Also dynamic counting should be teached to the largest partners, in order to avoid excessive counting trips.
	Define how responsibility for cycle counting tasks is shared between companies.	Partners 1 and 2 and Jüri should be given more responsibility in the future.
	Count by item / count by facility.	Counting by facility is more effective, but it requires warehouse transfers to be performed correctly.

Table 4-7 Recommended cycle counting decisions.

4.4.4. External Warehouse Decisions

If a new cycle counting policy is to be implemented using the ABC classification discussed above, there are still various ways how to use it at external warehouses. The question is whether to perform the analysis together for all plants or separately for each of them. This is an important issue because it determines how many counts will be performed at each location. Picture 4-9 shows how the amount of cycle counting work varies between systems. The information is based on the supply network's inventory situation, as it was in 4th March 2008 and a forecast of the expected number of stock keeping units for the year 2010 (appendix 11). The forecast is based on managers' perceptions of how operations will evolve. In this comparison a line to be counted is not the same as a stock keeping unit or item. A line to be counted is a SKU stored at a specific plant, multiplied with a class-specific factor, that is 4 times for class A items, 2 times for class B and 1 time for class C. For example, if item X is stored only at the main factory, it is one line to be counted multiplied by 4, 2 or 1. If however it would be stored at two locations, there would be two lines to be counted times 4, 2 or 1.. Thus the total number of lines to be counted can be obtained as following:

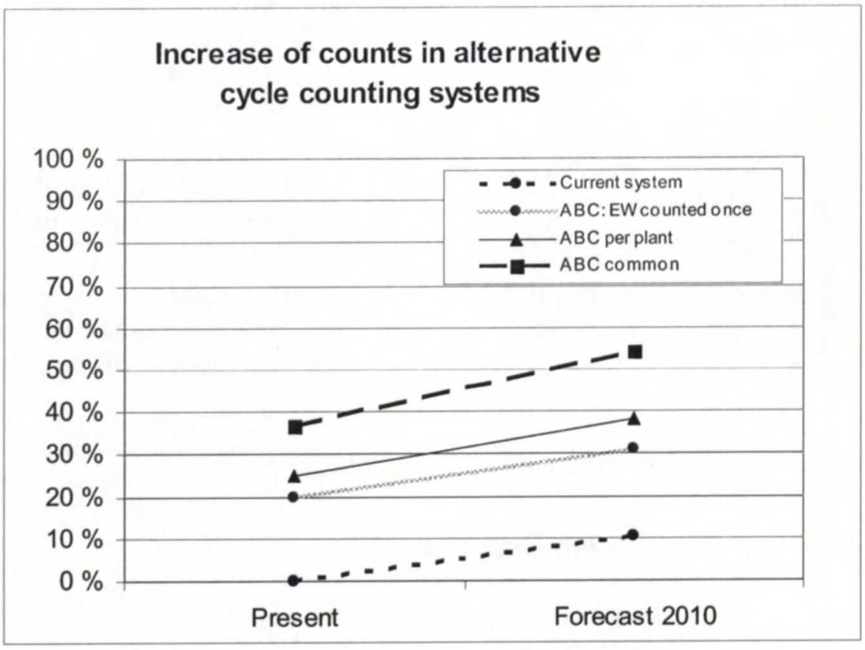
$$\text{Total number of lines to be counted} = \sum_{i=1}^{n}(\text{Number of locations stored}_i * \text{Count multiplier}_i)$$

where

n = number of SKUs

Count multiplier = 4 for class A, 2 for class B and 1 for class C

Formula 7 Total number of lines to be counted.



Picture 4-9 Number of lines to be counted in different counting systems.

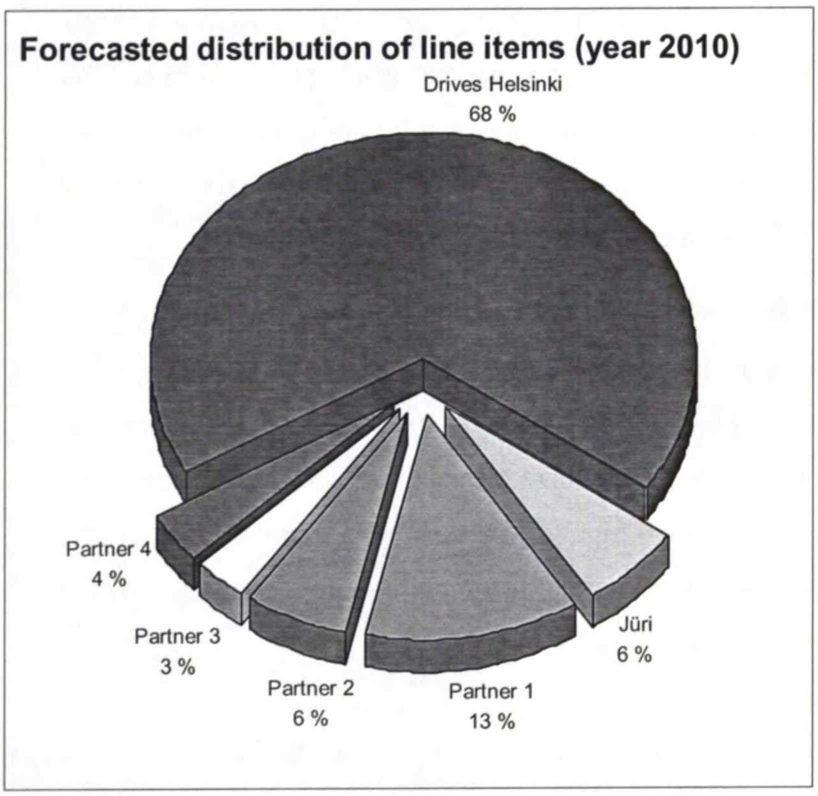
The following list explains the main differences between counting systems:

- **Current system:** All SKUs are counted only once. The number of counts will increase by 10 %.
- **ABC, external warehouses counted once:** ABC classification is made for the whole network at once, but A and B items are counted more often only at Drives Helsinki. Inventory accuracy in Drives' ERP system would not increase as much as in the other systems, but the approach would save work hours.
- **ABC per plant:** Each facility would perform its own ABC analysis and concentrate on the items most valuable to local operations. This approach would require only slightly more effort than counting external warehouses only once, but bring higher inventory accuracy. As ABC analysis can be performed automatically by the ERP system once the required parameters have been set, this would be an efficient way to allocate cycle counting resources.
- **ABC common:** ABC analysis would be performed at Drives Helsinki factory and the classification used as such in other facilities. As outsourced production lines tend to have high production volumes, items stored at external warehouses are often those with high usage values. Therefore there would be a lot of A items in the external warehouses, what would highly increase the number of counts. Implementing and applying this system would thus require more work than the other cycle counting policies presented here.

From the listed counting strategies, "ABC per plant" is the best. It is the most suitable way of prioritizing high-volume items specific to each plant. It has at least one problem though: ABB does not allow its partner companies to get access to price information. If the company intends to pass counting responsibility on to its partners, the ERP system's ABC analysis will have to be run in the backround so that outsiders can not see the usage values or prices. If this procedure is feasible in practice, it should be selected for implementation.

The following section is an example of how the External Warehouse Counting Options -model can be used in determining how to arrange counts in Drives' production network. The data in the example is real and it is used for assessing the best counting option for each warehouse. However it is meant to be used as a guideline and basis for discussion and decision making rather than being an optimal and final solution.

The network consists of the main factory Drives Helsinki, its Estonian production facility named Jüri and four partner companies which are not part of the ABB group. Picture 4-10 shows the proportional amounts of line items stored at these six facilities, as forecasted by ABB's material managers. Other plant-specific factors are listed in table 4-8.



Picture 4-10 Forecasted distribution of line items (year 2010).

	Jüri	Partner 1	Partner 2	Partner 3	Partner 4
Plant type	Production	Production & warehouse	Production & warehouse	Production	Production
Production process characteristics	Mainly small batches	Large & small batches	Mainly large batches	Small batches	Small batches
Number of item lines (forecast 2010)	6 %	13 %	6 %	3 %	4 %
Stock value 4.3.2008	5 %	13 %	28 %	2 %	1 %
Number of pieces 4.3.2008	5 %	11 %	18 %	1 %	1 %
Congruence of information systems	Same ERP	Limited ERP	Limited ERP	Limited ERP	Limited ERP
Company ownership	ABB	Other	Other	Other	Other
Travel time from ABB Drives Helsinki	> 3 hours	0,5 hours	0,5 hours	> 2,5 hours	1 hour

Table 4-8 Warehouse profiles.

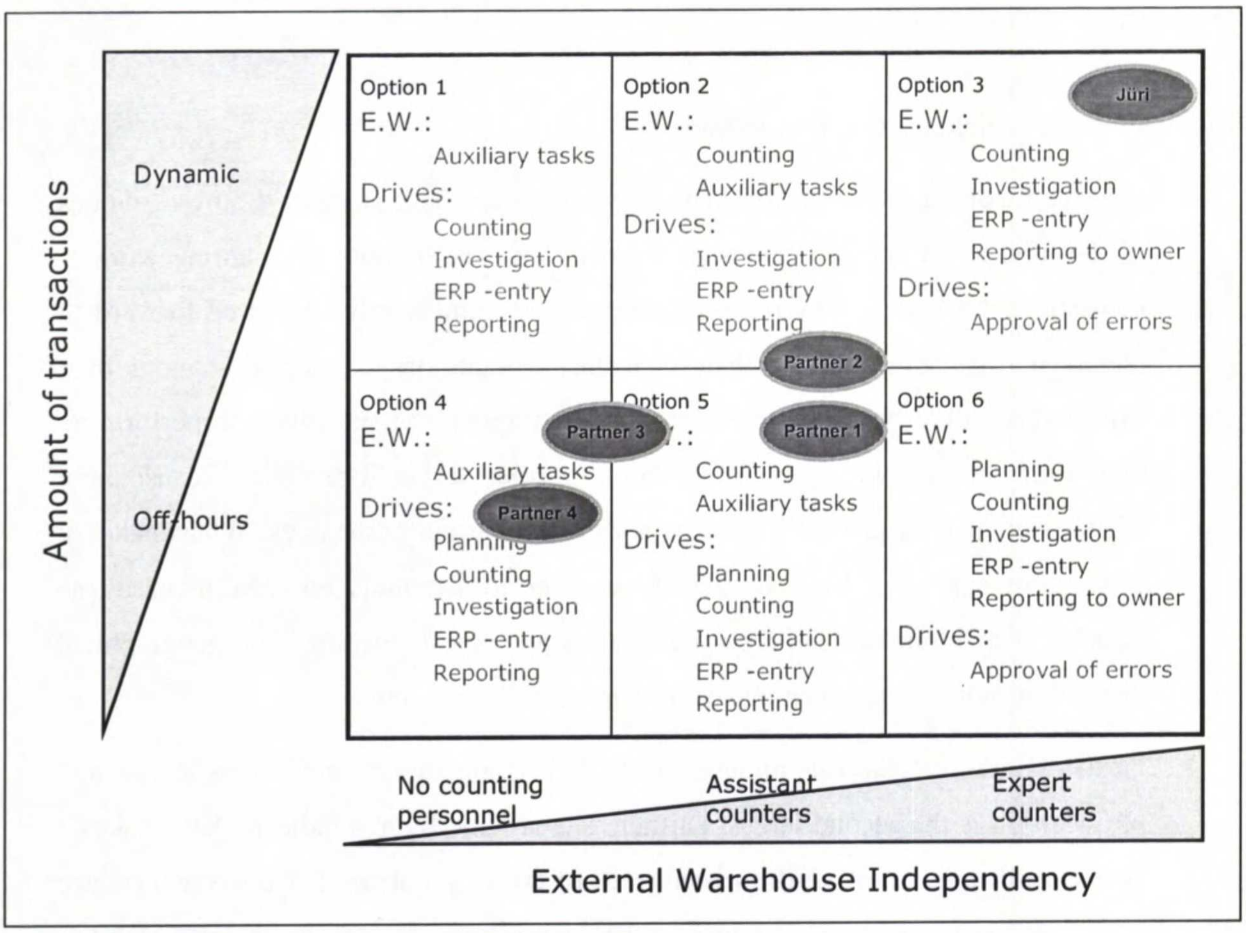
Summing up the warehouses look as follows:

- Jüri, the Estonian subsidiary of ABB Drives does not have such large stock volumes as the largest partner companies in the network. The amount of counting work is therefore not a reason why responsibility should immediately be passed forward to the local organization. Nevertheless, if Jüri's operations would grow more than expected it would become reasonable to start training the subsidiary to perform its own cycle counting activities. Also as a pilot project it would be easier because there are no similar data privacy issues than with the partner companies. What makes it even more appealing to teach Jüri how to perform counts on their own, is the possibility of eliminating the need for counting trips to Estonia. The geographical distance is quite long, which makes the trips time-consuming.
- Partner 1 has the largest amount of stock keeping units stored. Financially and physically it is the second largest partner. The volume figures indicate that it takes a considerable amount of work to keep track of errors at partner 1. However there are some data security and ERP discrepancy issues which complicate responsibility

sharing. Partner 1 is also situated fairly close to the main factory, so it is easy to visit when necessary.

- Partner 2 has the second largest amount of stock keeping units stored. Financially and physically it is the largest partner, which makes it heavy to count. However stock is kept mainly in large quantities, which speeds up routine counting work. Partner 1 is also situated fairly close to the main factory, so it is easy to visit when necessary.
- Partners 3 and 4 have the lowest material volumes according to all three indicators. Therefore they are not the largest burden to cycle counting personnel at Drives, except for the relatively long distance that employees must travel to partner 3.

Using the above information for selecting appropriate cycle counting strategies for each warehouse, the solution could look as follows (picture 4-11):



Picture 4-11 Drives' supply network in the EWCO model.

In the suggested solution, Jüri is selected for a pilot project. The idea is to start transferring knowledge about investigating errors and performing dynamic cycle counts. The aim is eventually to pass full responsibility of cycle counting work to Jüri so that local decision makers could schedule and perform counts flexibly using the same process as Drives, but executed by local employees (option 3). Drives would only act as a supervisor approving inventory errors as presented by Jüri.

Depending on the pilot project's success, also other companies in the network could start taking more responsibility of their own stock. Partner 2, having a large part of the stock in bulk quantities, could partially apply the dynamic counting method (situating between options 2 and 5 in the model). Nevertheless, off-hour counting is generally a better alternative because of its advantages listed in chapter 4.3.1. It requires less ERP investigation and is usually more effective.

5. Conclusions

At first, one might think that inventory accuracy is a simple and narrow subject. Cycle counting is often viewed as something that any worker can do. When taking a deeper look, however, there are a lot of interrelated factors that make the creation of an efficient accuracy strategy surprisingly difficult and complicated. Especially in today's operating environment, with outsourced activities and automatic ERP processes, verifying stock levels is a time-consuming and challenging task. On the other hand, neglecting to maintain accuracy quickly results in costly problems, as production interruptions and last-minute rescheduling, excessive holding costs and other inconveniences, possibly even late deliveries to customers and lost sales. At a minimum level, faulty inventory records disturb daily routines and waste people's time.

5.1. Increased Visibility to the Quality of Material Processes

As soon as any transaction process has a fault, it is reflected in a decreased accuracy level. Therefore inventory accuracy can be viewed as a quality indicator of the company's material processes. After all, inventory accuracy eventually captures all the processes of an inventory management system. This is a good reason why accuracy should be measured: To evaluate how well the material processes are in control.

In the chapter 3 measures of accuracy from previous research were presented. Of these measures *the overall accuracy level* and *the weighted on-hand error percentage* were applied in the case company to get an objective understanding of the accuracy situation at ABB Drives. These measures, along with most of the others introduced, are relatively easy to calculate for any given company. The input needed in these calculations is ordinary warehouse data that should be available in most companies. For any company having troubles with inventory processes, measuring inventory accuracy and setting targets is therefore a good starting point for improvement efforts.

5.2. Recommendations for the Case Company

The use of ABC analysis for guiding cycle counting efforts was discussed extensively. ABC analysis proved out to be a useful tool that can easily be implemented for directing counting efforts more effectively. Various ABC classification factors from previous literature were introduced, while their suitability was further analyzed in the case study. One factor, *usage value*, was selected for performing the automatic classification in the case company's ERP system. This method can be complemented by manually locking an item to the A-class based on its criticality or past error tendency.

Recommendations for an accuracy strategy were given for the case company and a framework, the EWCO –model was developed for aiding decision makers in selecting appropriate counting strategies for external warehouses. The key questions for external warehouses are the division of counting tasks between supply network members and the choice between dynamic and off-hour counts. The EWCO –model was also applied to the case company, suggesting an initial approach for sharing cycle counting responsibility within its partner network.

The cycle counting process of the case company was mapped and an improved cycle counting process was developed. New process phases include the planning of off-hour counts, the ABC classification method and a reporting procedure for removing error causes from material processes, thus increasing accuracy in the long term.

5.3. General Findings

This study defines all the major elements of an inventory accuracy strategy. The contribution to the research fields of inventory management and data accuracy comes from listing the key decisions a company must assess when developing an accuracy strategy, as well as introducing the EWCO –model, which captivates the essential elements related to cycle counting in today's multi-company environment. It should help managers see the larger context of the production network and support inventory accuracy -related decision making. There is clearly a research gap where it comes to controlling inventory held at external warehouses operated by a separate company. Along with the emerge of logistics service providers and the trend towards outsourcing operations to them, new controlling problems are unfolding. How these would best be solved, is yet to be resolved. Coordinating a production network while bearing in mind operational efficiency, the technical problems of an ERP environment and data privacy issues between network members is not an easy challenge.

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7. Appendices

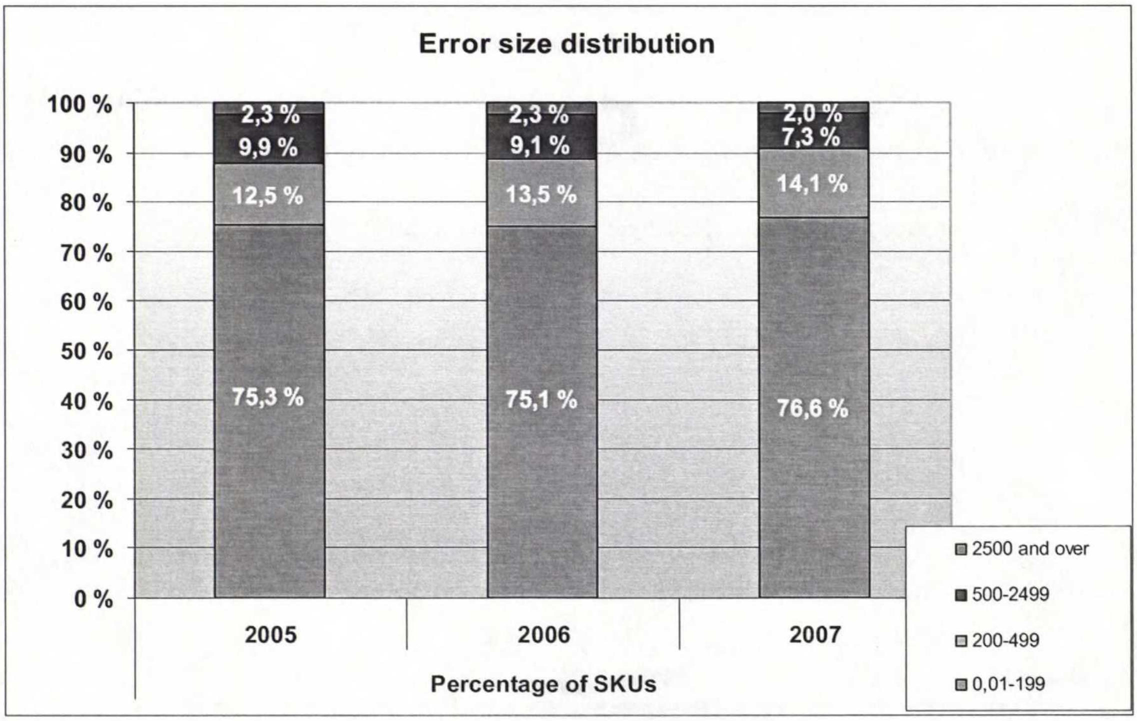
Appendix 1

Appendix 1: Cycle counting decisions in previous literature

Cycle Counting Decisions		Previous research appearance (theoretical and managerial)
General Decisions	Measure accuracy and set targets.	Mikkola (2006), Dehoratius & Raman (2004), Piasecki (2003), Neeley (1987), Bernard (1985), Schrady (1970).
	Define cycle intervals.	Kök & Shang (2007), Latham (2003), Neeley (1987), Morey (1985), Iglehart & Morey (1972).
	Select ABC factors and set items to classes.	Kök & Shang (2007), Krajewski (2005), Dehoratius & Raman (2004), Heizer & Render (2004), Latham (2003), Piasecki (2003), Brown et al. (2001), Silver et al. (1998), Sheppard & Brown (1993), Flores & Whybark (1987), Neeley (1987), Bernard (1985).
	Select between dynamic / off-hour counting method for individual production lines.	Piasecki (2003).
	Define error investigation and reporting methods.	Kuipers et al. (2004), Latham (2003), Latham & Williams (2003), Piasecki (2003), Bernard (1985).
External Warehouse Decisions	Select between dynamic / off-hour counting method for each facility.	None
	Define how responsibility for cycle counting tasks is shared between companies.	None
	Count by item / count by facility.	None

Appendix 2: Inventory error distribution by size

	Percent of SKUs		
Inventory error size	**2005**	**2006**	**2007**
0,01-199	75,3 %	75,1 %	76,6 %
200-499	12,5 %	13,5 %	14,1 %
500-2499	9,9 %	9,1 %	7,3 %
2500 and over	2,3 %	2,3 %	2,0 %



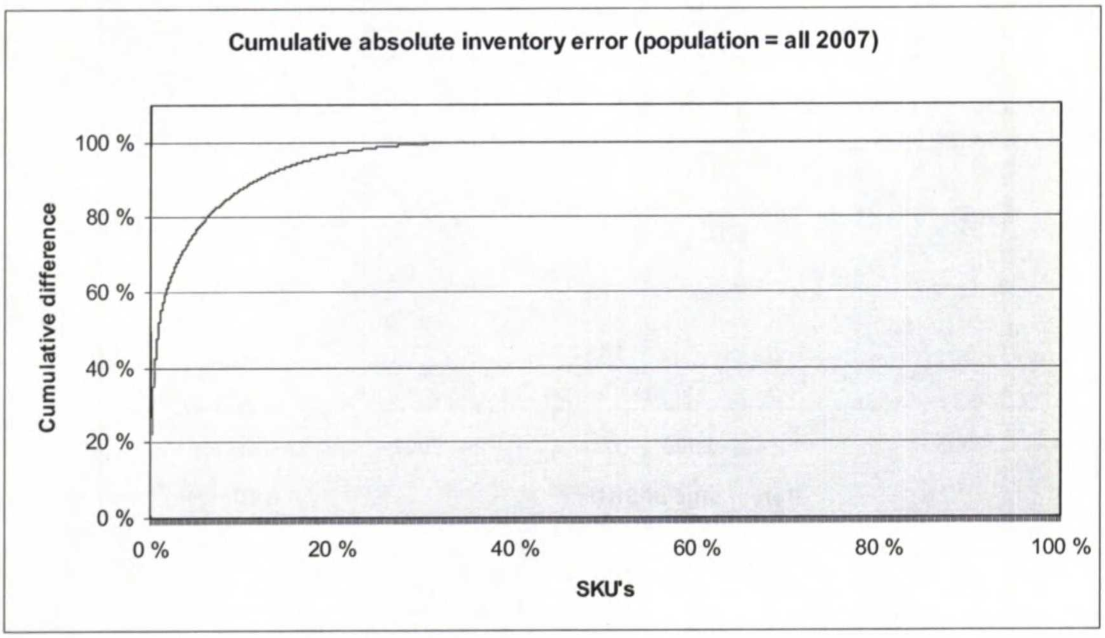
Appendix 3

Appendix 3: Growth in sales, number of stock keeping units and stock levels

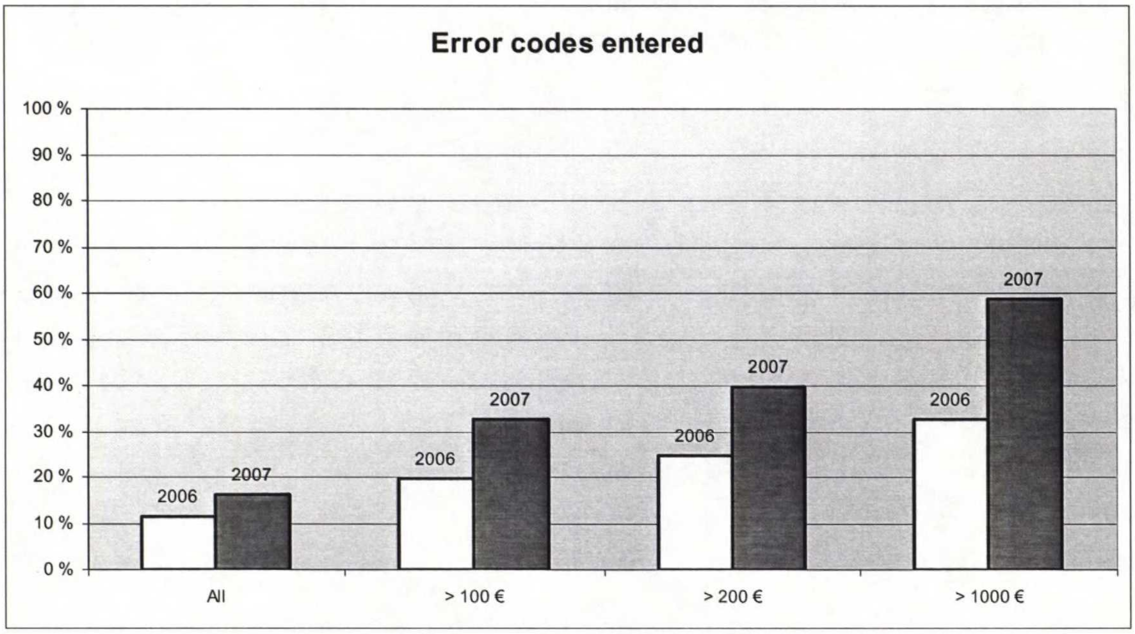
	2006	2007
Sales	+ 35 %	+ 40 %
Number of SKUs	- 4 %	+ 19 %
Stock value	+ 56 %	+ 74 %
Amount of pieces stored	+ 3 %	+ 22 %

Appendix 4

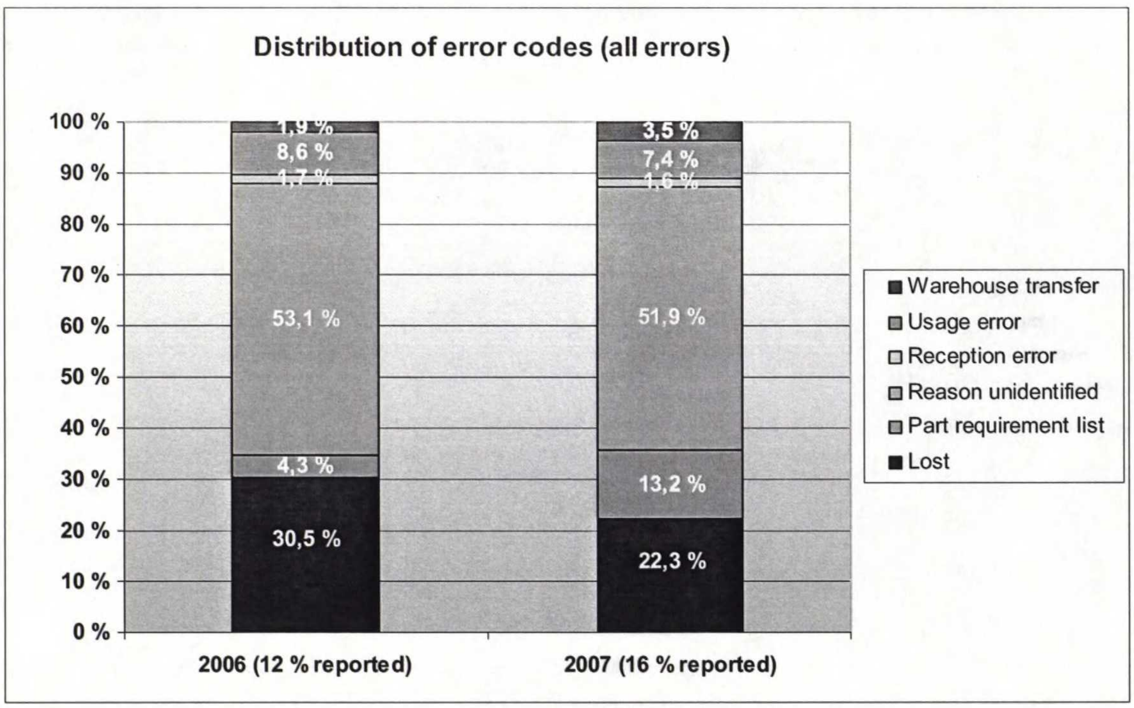
Appendix 4: Pareto curve for cumulative absolute inventory errors in 2007



Appendix 5: Error codes entered



Appendix 6: Error cause distribution



Appendix 7: Business Unit Level Effects of Alternative Counting Policies

1. Allocation to ABC classes

	10/20/70	15/25/60	20/30/50
A	10 %	15 %	20 %
B	20 %	25 %	30 %
C	70 %	60 %	50 %
	100 %	100 %	100 %

2. Number of items counted

	10/20/70	15/25/60	20/30/50	Counts per year
A	0,4	0,6	0,8	4 x
B	0,4	0,5	0,6	2 x
C	0,7	0,6	0,5	1 x
Current duplicate counts	0,1	0,1	0,1	
Count multiplier	1,4	1,6	1,8	

This means that the number of counts in the new system is 1.4, 1.6 or 1.8 times higher compared to the original situation.

Average counting speed (full-time counters) 3863 SKUs per year

3. Man-years

		Pessimistic	Neutral	Optimistic
	Counting speed	3000	4000	5000
	Current system (1x per year)	3,8	2,9	2,3
A/B/C	10/20/70	5	4	3
	15/25/60	6	5	4
	20/30/50	7	5	4

4. Increase in man-years

		Pessimistic	Neutral	Optimistic
	Counting speed	3000	4000	5000
A/B/C	10/20/70	1,4	1,1	0,8
	15/25/60	2,3	1,7	1,4
	20/30/50	3,1	2,3	1,9

		Increase in man-years		
		Min		Max
A/B/C	10/20/70	0,8	-	1,4
	15/25/60	1,4	-	2,3
	20/30/50	1,9	-	3,1

Max	3,1
Min	0,8

5. Theoretical labor cost

		Pessimistic	Neutral	Optimistic
Counting speed		3000	4000	5000
Current system (1x per year)		161 000	120 750	96 600
	10/20/70	220 282	165 212	132 169
	15/25/60	258 587	193 940	155 152
A/B/C	20/30/50	290 909	218 182	174 545

6. Increase in labor cost

		Pessimistic	Neutral	Optimistic	
	Counting speed	3000	4000	5000	Average
	10/20/70	59 282	44 462	35 569	46 438
	15/25/60	97 587	73 190	58 552	76 443
A/B/C	20/30/50	129 909	97 432	77 945	101 762

Changing the Number of Counts

Allocation to ABC classes

	10/20/70	15/25/60	20/30/50
A	10 %	15 %	20 %
B	20 %	25 %	30 %
C	70 %	60 %	50 %
	100 %	100 %	100 %

Policy: 12A, 6B, 1C

	10/20/70	15/25/60	20/30/50	Counts per year	
A	1,2	1,8	2,4	12	x
B	1,2	1,5	1,8	6	x
C	0,7	0,6	0,5	1	x
Current duplicate counts	0,1	0,1	0,1		
Count multiplier	3,0	3,8	4,6		

Policy: 10A, 4B, 1C

	10/20/70	15/25/60	20/30/50	Counts per year	
A	1	1,5	2	10	x
B	0,8	1	1,2	4	x
C	0,7	0,6	0,5	1	x
Current duplicate counts	0,1	0,1	0,1		
Count multiplier	2,4	3,0	3,6		

Policy: 4A, 1B, 1C

	10/20/70	15/25/60	20/30/50	Counts per year	
A	0,4	0,6	0,8	4	x
B	0,2	0,25	0,3	1	x
C	0,7	0,6	0,5	1	x
Current duplicate counts	0,1	0,1	0,1		
Count multiplier	1,2	1,4	1,5		

Policy: 2A, 1B, 1C

	10/20/70	15/25/60	20/30/50	Counts per year	
A	0,2	0,3	0,4	2	x
B	0,2	0,25	0,3	1	x
C	0,7	0,6	0,5	1	x
Current duplicate counts	0,1	0,1	0,1		
Count multiplier	1,0	1,1	1,1		

Count multiplier range

Max	4,6
Min	1,0

Conclusions for appendix 7 (Business unit –level work increase)

The amount of counting work would increase by 40-80 % in the short term. In labor hours this means an additional 1 to 3 man-years, depending how items would be assigned to ABC classes and how efficient the work would be. If all the extra work would be performed by new personnel, this would mean a labor cost increment of 40 000 to 130 000 euros.

In reality work would become more effective, especially because errors could be investigated sooner than before and would thus be easier to solve.

Labor costs would not increase as much as calculations suggest, because part of the added work would be performed by old employees. Employment needs would need to be measured separately for each department.

Counting external warehouses would need to be addressed separately, because counting them requires planning and takes time. It would probably not be feasible to organize e.g. four counting trips per year to Estonia.

Appendix 7-5

Calculation presumptions:

Count multiplier

A number used for determining the amount of counting work under different cycle counting policies. For example a count multiplier value of 1,4 means that the policy requires 40 % more counts compared to the original setting.

Counting speed:

Average number of SKUs counted by one full-time cycle counter during a year, weighted average 2005-2007 (weights: 2007 = 0.5, 2006 = 0.3, 2005= 0,2)

Optimistic, neutral and pessimistic counting speeds (4 000, 5 000 and 3 000) are based on the average speed.

Counting speed calculations include needed slack for meetings, breaks etc., because the calculations are based on yearly work-hours instead of keeping time of actual counting work. Therefore slack does not have to be included in possible further calculations.

Man-years:

Number of SKUs (11 500) divided by counting speed.

Labor cost:

Estimated monthly labor cost per person = 3 500 €

Yearly labor cost / person = 3 500 x 12 = 42 000 €

Total labor cost = 42 000 * man-years

Appendix 8: Evaluating the predicting value of multiple locations

Number of storage locations	Total net error	Total absolute error	SKUs	Erroneous SKUs	Percentage of erroneous	Average error
6	194,86	194,86	1	1	100,0 %	194,86
5	0	0	2	0	0,0 %	0,00
4	-9243,37	10433,25	93	32	34,4 %	112,19
3	-3390,4	7316,3	197	67	34,0 %	37,14
2	11918,03	149801,85	1413	575	40,7 %	106,02
1	-239848,85	1254439,25	10344	3974	***38,4 %***	***121,27***
1<	-520,88	167746,26	1706	675	***39,6 %***	***98,33***

The percentage of erroneous items is only slightly higher for items stored in more than one location than for items stored only at one place (39,6 % vs. 38,4%). Average error is actually smaller (98,33 and 121,27). Therefore multiple locations does not have significant predicting value for inventory errors.

Appendix 9: ABC classification by usage value

ABC classification 2007 - Example

Column number 1	2	3	4	5	6	7
Rank number	% of SKUs	Class	Usage value	ABS Net error	Cumulative	Cumulative %
1	0,01 %	1	58 274 832	250,18	250,18	0,02 %
2	0,02 %	1	8 505 297	831,6	1081,78	0,08 %
3	0,03 %	1	2 898 378	1033,57	2115,35	0,16 %
4	0,04 %	1	2 847 611	270	2385,35	0,18 %
5	0,05 %	1	2 734 958	721,79	3107,14	0,23 %
6	0,06 %	1	2 572 218	131,2	3238,34	0,24 %
7	0,06 %	1	2 496 727	565,25	3803,59	0,28 %
8	0,07 %	1	1 972 832	0	3803,59	0,28 %
9	0,08 %	1	1 962 139	0	3803,59	0,28 %

Step 1: Calculate usage value (column 4) for each SKU by multiplying piece usage with item price.

Step 2: Find the corresponding absolute inventory error records for each item (column 5). If an item has been counted multiple times that year, all these counts should be summed so that positive and negative variances balance each other. Otherwise items counted more often will have a larger error frequency and magnitude. The summed error should be shown as an absolute value for making comparison possible.

Step 3: SKUs are sorted in a decreasing order based on usage value.

Step 4: Rank numbers are given for each SKU (column 1). The cumulative percentage of SKUs is then counted (column 2), as well as cumulative ABS net error percentage (columns 6 and 7).

Step 5: ABC analysis is done by comparing columns 2 and 7 to see what proportion of SKUs is sufficient to cause the majority of cumulative inventory error. Also linear correlation is calculated with a basic spreadsheet function. For example:

ABC analysis - usage value 2007	
Cum. error percentage	Reached at
50 %	4 %
75 %	13 %
90 %	40 %
99 %	91 %

Linear correlation	0,80

Linear correlation was calculated with Microsoft Excel's *correl* –function, which uses the following formula (Pearson's linear correlation):

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

Formula 8 Pearson's linear correlation.

Appendix 10: Evaluating the predicting value of past inventory errors

Predicting value of previous inventory errors - Example 2006 vs. 2007

Column number 1	2	3	4	5	6	7	8
Rank number 07	**Material 07**	**Difference abs.**	**Rank number 06**	**Material 06**	**VLookUp 06**	**d**	**d^2**
1	Material 1	38615,19	61	Material 1	27479,25	60	3600
2	Material 2	32639,42	4	Material 2	19416,12	2	4
3	Material 3	25458,44	19	Material 3	14833,38	16	256
4	Material 4	24008,88	236	Material 4	13953,40	232	53824
5	Material 5	16357,38	96	Material 5	12558,23	91	8281
6	Material 6	12093,76	106	Material 6	12426,58	100	10000
7	Material 7	12025,19	180	Material 7	12254,31	173	29929
8	Material 8	10303,44	162	Material 8	9626,69	154	23716
9	Material 9	9628,49	1223	Material 9	9394,21	1214	1473796

Step 1: Inventory errors are plotted for the two years compared (columns 2, 3, 5 and 6).

Step 2: Data is sorted in a decreasing order based on inventory errors in the latter year (2007, column 3). Rank numbers are given to SKUs (columns 1 and 4)

Step 3: Microsoft Excel's VLookUp -function is used for determining corresponding values of inventory errors of the previous year (2006 in this case, column 6).

Step 4: Data for the predicting year (2006, columns 4, 5 and 6) are sorted in a decreasing order based on inventory errors (column 6). Rank numbers for the predicting year are mixed (column 4).

Step 5: The d-factor needed in the rank correlation formula is calculated (Rank number 06 - Rank number 07, column 7).

Step 6: The d factor is raised to the power of two (column 8).

Step 7: Spearman's rank corrrelation coefficient is calculated with the following formula:

Appendix 10-2

Spearman's rank correlation coefficient:

$$\boxed{\rho = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n\left(n^2 - 1\right)}}$$

Formula 9 Spearman's rank correlation coefficient.

Results for years 2006 and 2007:

2006 & 2007	
ρ	67,41 %
n	1907

This means that 1907 SKUs in total had an inventory error in both years. Correlation was 0,67, which is meaningful.

Appendix 11: Amount of lines to be counted in different ABC systems

1. Present situation, alternative counting practices, ABC classes set once

		Partner 1	Partner 2	Partner 3	Partner 4	Jüri	Drives Helsinki	Current	ABC 4/2/1	External only once
								Number of counts		
No. of SKUs	A	228	232	17	34	75	602	1 188	4 752	2 994
	B	393	172	37	102	125	1 205	2 034	4 068	3 239
	C	1 048	175	162	126	225	10 243	11 979	11 979	11 979
Total per warehouse		1 669	579	216	262	425	12 050	**15 201**	**20 799**	**18 212**

= 228 + 232 + 17 + 34 + 75 + 602 = 1 188

= 1 188 x 4 = 4 752

= 2 034 x 2 = 4 068

= 228 + 232 + 17 + 34 + 75 + 602 x 4 = 2 994

2. Proportions of ABC classes in facilities

	Partner 1	Partner 2	Partner 3	Partner 4	Jüri	Drives Helsinki
A	14 %	40 %	8 %	13 %	18 %	5 %
B	24 %	30 %	17 %	39 %	29 %	10 %
C	63 %	30 %	75 %	48 %	53 %	85 %
Total per warehouse	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**

= 75 / 425 = 0,18

Estimates given by the case company

= 75 + 0,18 x 300

3. Forecasted n. of SKUs for year 2010

		Partner 1	Partner 2	Partner 3	Partner 4	Jüri	Drives Helsinki	N. of counts Forecast	ABC 4/2/1	External only once
Estimated increase		*200*	*200*	*200*	*200*	*300*	*500*	*1600*		
No. of SKUs	A	255	312	33	60	128	627	1 415	5 660	3 296
	B	440	231	71	180	213	1255	2 391	4 782	3 646
	C	1174	235	312	222	384	10668	12 995	12 995	12 995
Total per warehouse		1 869	779	416	462	725	12 550	**16 801**	**23 437**	**19 937**

= 255 + 312 + 33 + 60 + 128 + 627 = 1 415

= 2 391 x 2 = 4 782

= 255 + 312 + 33 + 60 + 128 + 4 x 627 = 3 296

4. Present ABC class sizes if classification is made for each plant separately

Present stock situation

		Partner 1	Partner 2	Partner 3	Partner 4	Jüri	Drives Helsinki	Total	Number of Counts
No. of SKUs	**A**	83	29	11	13	21	603	760	3 040
	B	167	58	22	26	43	1 205	1 520	3 040
	C	1 419	492	184	223	361	10 243	12 921	12 921
Total per warehouse		1 669	579	216	262	425	12 050	**15 201**	**19 001**

= Sum row

= 1 520 x 2

5. Forecasted ABC class sizes when classification is made for each plant separately

Forecasted stock situation

		Partner 1	Partner 2	Partner 3	Partner 4	Jüri	Drives Helsinki	Total	Number of Counts
No. of SKUs	**A**	93	39	21	23	36	628	840	3 360
	B	187	78	42	46	73	1 255	1 680	3 360
	C	1 589	662	354	393	616	10 668	14 281	14 281
Total per warehouse		1 869	779	416	462	725	12 550	**16 801**	**21 001**

= 840 x 4

= 1 680 x 2

= 779 x 0,005 = 39

= 462 x 0,1 = 46

= 462 x 0,1 = 46

Summary of amount of lines to be counted:

Number of counts	Present	Forecast 2010
Current system	15 201	16 801
ABC: EW counted once	18 212	19 937
ABC per plant	19 001	21 001
ABC common	20 799	23 437
Change from present situation	Present	Forecast 2010
Current system	0 %	11 %
ABC: EW counted once	20 %	31 %
ABC per plant	25 %	38 %
ABC common	37 %	54 %
Work increase in man-years	Present	Forecast 2010
Current system	0,0	0,5
ABC: EW counted once	0,9	1,4
ABC per plant	1,1	1,7
ABC common	1,6	2,4

= (21 001 - 15 201) / 3500

Current SKU figures are based on actual physical stock situation 4th March 2008.

Forecasts are estimates made by ABB Drives.